치의학박사학위논문

Influence of finish line design on the marginal fit of nonprecious metal alloy coping fabricated by 3D printing, milling and casting using CAD/CAM

CAD/CAM 을 활용하여 3D printing, milling, casting 방법으로 제작한 비귀금속 합금 코핑의 지대치 변연 형태에 따른 변연 적합도의 변화

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김 서 랑

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ABSTRACT

Influence of finish line design on the marginal fit of nonprecious metal alloy coping fabricated by 3D printing, milling and casting using CAD/CAM

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Purpose: The purpose of this study was to examine the correlation between the finish line designs and the marginal adaptation of nonprecious metal alloy coping produced by different digital manufacturing methods. With this view, one master model with deep chamfer margin and another master model with rounded shoulder margin were fabricated and this study was aimed to compare the correlation depending on the three different manufacturing methods of selective laser sintering, milling and casting.

Materials and methods: For fabrication of two master models with different finish lines, the master models were designed by 3-D designing software program based on the abutment preparation principle and titanium master models were milled by computer aided manufacturing. Nonprecious metal alloy copings were made respectively from each master model with three different methods; selective laser sintering (SLS), milling and casting by CAD/CAM. 12 copings were made by each method resulting in 72 copings in total. The marginal fit was evaluated by

measuring the gap between the cavosurface margin of the abutment die and the edge of the crown margin on mesial, buccal, distal and lingual site of each specimen. The measurement was conducted at 40 determined reference points along the circumferential margin with the confocal laser scanning microscope at magnification x150.

Results: Mean values of marginal gap of laser sintered copings were 11.8±7.4 μm for deep chamfer margin and 6.3±3.5 μm for rounded shoulder margin and the difference between them was statistically significant (p<.0001). Mean values of marginal gap of milled copings were 53.9±27.8 μm for deep chamfer margin and 48.6±30.1 μm for rounded shoulder margin and the difference between them was not significant (p=.279). Mean values of marginal gap of casted copings were 18.8±20.2μm for deep chamfer margin and 33±20.5 μm for rounded shoulder margin and the difference between them was significant (p=.0004). Meanwhile, the marginal fit depending on the manufacturing method was significantly different regardless of finish line design. Selective laser sintering group exhibited the best marginal adaptation among three manufacturing methods and digitalized casting group showed better marginal fit than milling group.

Conclusion: Within the limitation of this study, the following conclusions were drawn.

1. The variation of finish line design influences the marginal fit of laser sintered metal coping and casted metal coping.

2. Laser sintered copings with rounded shoulder margin had better marginal fit than deep chamfer margin.

3. Casted copings with deep chamfer margin had better marginal fit than rounded shoulder margin.

4. No significant difference on the marginal fit was found between deep chamfer margin and rounded shoulder margin in milled metal coping.

5. According to the manufacturing method, SLS system showed the best marginal fit among three different methods. Casting and milling method followed that in order.

Key words : CAD/CAM , 3D printing, selective laser sintering, nonprecious alloy coping , marginal fit

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INTRODUCTION

The use of nonprecious metal alloys as dental materials is increasing owing to the expensive cost of precious metal alloy. The most widely used base metal alloys are Cobalt-Chrome (Co-Cr) alloy and Nickel-Chrome (Ni-Cr) alloy. Co-Cr alloy has been generally used for metal framework of removable partial denture, as the material is rigid enough for the intraoral functioning, resistant to corrosion, less allergenic than Ni-Cr alloy and more economic compared with noble metal alloys.[1-3] However, certain properties of it such as high melting range, low ductility[4,5] and Chrome oxide layer of surface[6,7] make the casting process of it difficult and generate errors. In comparison, Ni-Cr alloy has been used for metal coping of porcelain fused to metal crown as a substitute of precious alloy, because it has higher bond strength to porcelain than Co-Cr alloy and a similar thermal expansion to gold alloy and higher strength than precious metal alloy for long span prostheses.

The traditional lost wax casting has been the most common method of fabricating metal alloy for many decades,[8] but errors accumulate in the series of laboratory steps including the expansion and contraction of the impression materials, gypsum, wax, investment, and alloy. These accumulated errors result in the inaccuracy of the prostheses consequentially.[9]

Meanwhile, as digital dentistry has been advanced rapidly, many parts of the dental works can be digitalized such as intraoral digital impression, producing stereolithographic model, virtual articulation and computer-aided design/computer-assisted manufacturing (CAD/CAM) of prosthesis. Especially, CAD/CAM system has been developed a lot and becomes more popular for recent decades.[10] It was to reduce the error occurring in the manual laboratory steps.[11] CAD/CAM milling is a subtractive method of milling block-shaped materials with diamond rotary instruments. The advantage of this method is time saving because multiple producing is possible at the same time and it simplifies many steps of conventional procedure,[12] whereas the waste of materials and the wear of milling burs can be its disadvantages.

There are numerous CAD/CAM systems for the scanning and the corresponding milling procedures used in different dental applications. The Procera® system (Nobel Biocare AB, Göteborg, Sweden) introduced in 1991 was developed for manufacturing individualized dental restorations with networked CAD/CAM systems. CEREC® system (Sirona Dental System LLC, Blenheim, Germany) was also introduced for chair side use as a compact machine set.[7] Following them, Pro 50® system (Cynonad Inc., Montreal, Canada), DCS Dental® (DCS Dental AG, Allschwil, Switzerland), Everest® (Kavo Dental GmbH, Biberach, Germany), Cercon smart ceramics® system (DeguDent GmbH, Hanau, Germany), and LAVA® system (3M ESPE Dental AG, St. Paul, MN, USA) etc. have been introduced and mainly utilized for diverse dental applications.[12] Nevertheless, accurate digitalization of the information and industrial manufacturing of restorations remain challenging and require continuous quality assessments.[11,13,14]

In comparison with the milling method, selective laser sintering (SLS) is recently introduced as a manufacturing technology in dentistry. SLS is one of the rapid prototyping production methods, which fuses metal powder on to a solid part by melting it selectively using the focused laser beam and adds up layer by layer based on the CAD data.[5] This new technology has been used to produce substructures for metal ceramic crown and partial fixed dental prosthesis from Co-Cr base alloys and Au-Pt noble alloys [15-17] and also applied to make dental models out of pigmented polyamide powder. It is contrast to the milling technique in that it is basically an additive method and has no limitation of designing 3-D shapes with complex geometry.[18] Furthermore, the SLM metal copings have been reported to have satisfactory mechanical and chemical properties.[19-22] Nevertheless, this method is not popular owing to the expensive cost of the apparatus yet and the application of more various dental materials is needed.

There are several laser sintering systems being applied to dentistry at present; EOSINT M270 (EOS GmbH – Electro Optical Systems, Krailling, Germany),[5,23,24] FORMIGA P110 (EOS GmbH – Electro Optical Systems, Krailling, Germany), ProX 100 Dental (3D Systems, South Carolina, USA), EnvisionTEC 3Dent (EnvisionTEC® , Marl, Germany), AM250 (Renishaw plc, Gloucestershire, UK), PM 100 Dental System (PHENIX Systems, Clermont-Ferrand, France),[2,6,15] and BEGO MEDIFACTURING System (BEGO Medical, Bremen, Germany).[2,25] PM 100 Dental System (PHENIX Systems, Clermont-Ferrand, France) is the first manufacturing system using laser melting technique of cobalt-chromium powder for dental laboratory fabrication of prostheses.[2] EOSINT M270 (EOS GmbH – Electro Optical Systems, Krailling, Germany) is the first known dental laser sintering apparatus in Korea and was used in this study.

The marginal fit is one of the key factors for the clinical success of dental restorations.[26-29] Ideal marginal adaptation can reduce gingival irritation[30] and cement dissolution.[31] After clinically examining over 1000 metal ceramic crowns, McLean and von Fraunhofer[32] reported that marginal discrepancies up to 120 μm were acceptable. Other clinicians considered a marginal fit of 100 μm to be clinically acceptable for the longevity of the restorations.[33,34]

Regard to the factors affecting to the marginal adaptation, some studies have shown that the marginal adaptation of metal-ceramic crowns is influenced by the type of finish line.[35-37] Omar reported that the marginal adaptation of a shoulder-bevel metal-ceramic crown was significantly better than that of a metal-ceramic crown with a 90-degree shoulder.[37] However, other authors have reported that the marginal design or finish line design had no influence on the marginal adaptation of metal-ceramic crowns.[38,39] Meanwhile, there are several studies about the influence of finish line design on the marginal adaptation of gold crown. Gavelis et al. studied the effect of seven finish lines on the marginal seal and reported 41μm of shoulder margin and 44μm of chamfer margin for gold crown.[40] Shiratsuchi et al. concluded that the marginal adaptation of electroformed gold copings was significantly affected by the finish line design and suggested that a deep chamfer and a rounded shoulder design facilitate marginal adaptation in comparison to a shoulder design and may be preferred for metal ceramic crowns.[41] Based on these results, this in vitro study chose rounded shoulder margin and deep chamfer margin appropriate for anterior and posterior tooth preparation.

Many studies about the clinical acceptability of SLS technique have been conducted so far, particularly regard to the accuracy of the marginal adaptation. Quante et al. reported that no statistically significant differences between base metal alloy and precious alloy according to the marginal and internal fit of copings produced with laser melting technology was found.[15] Kim et al. concluded that no significant difference was found between the measurements of marginal fit of three-unit fixed dental prostheses fabricated using a direct metal laser sintering system and that of three-unit prostheses by a conventional lost wax technique method.[42] They also showed in another study that the gap of the metal cores produced by SLS increased after completion of porcelain firing on the metal core, but the gap was still acceptable clinically.[43] Meanwhile, Sundar,[44] Bhaskaran,[45] Castillo-Oyagüe et al.[46,47] reported the best marginal fit of SLS group than other manufacturing methods. Most studies mentioned above concluded that SLS Co-Cr may be a reliable alternative to the casted base metal alloys to obtain well-fitted crowns.[15, 43-48]

However, there has been little information on the relationship of the finish line design and the marginal fit of the SLS restoration. The purpose of this study was to evaluate the influence of the variation of finish line to the marginal adaptations of metal copings manufactured by SLS technique, milling and digitalized casting. The null hypotheses of this study stated that the finish line design do not influence the absolute marginal discrepancy of metal coping fabricated by three different methods and that the marginal fit of laser sintered coping is similar to that of casted coping and milled coping.

MATERIALS AND METHODS

Fabrication of master models

Two master models were designed by computer program (3D CAD, Dassault Systèmes SOLIDWORKS Corp., Massachusetts, USA) to simulate the complete crown preparation of the mandibular first molar (Fig. 1). Each design was represented on the titanium model by computerized milling (Fig. 2). Each model had 5.0 mm of height, 11.0 mm of maximum mesio-distal width, 10.0 mm of maximum bucco-lingual width and 1.2 mm of marginal width. They had 6 degrees of the convergent angle of axial wall and occlusal appearance of the prepared abutment tooth in common. The difference between two models is the axiogingival internal line angle, which represents the finish line design. One master model has deep chamfer margin with axiogingival internal line angle of 1.2 mm radius and the other one has rounded shoulder margin with axiogingival internal line angle of 0.5 mm radius (Fig. 3).

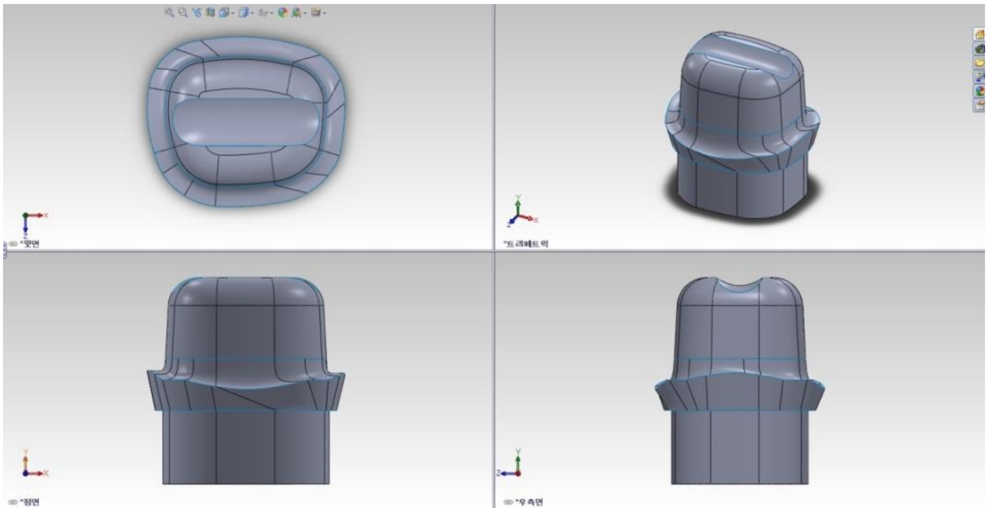


Fig. 1. The design of master model by 3D CAD program.

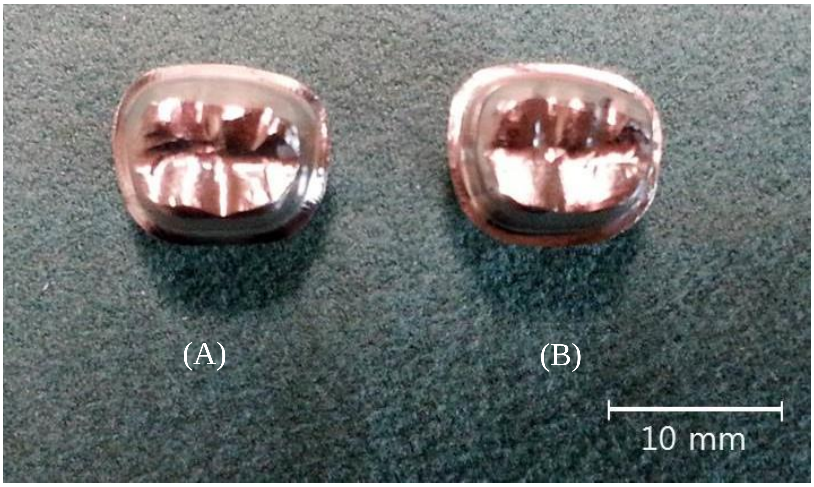
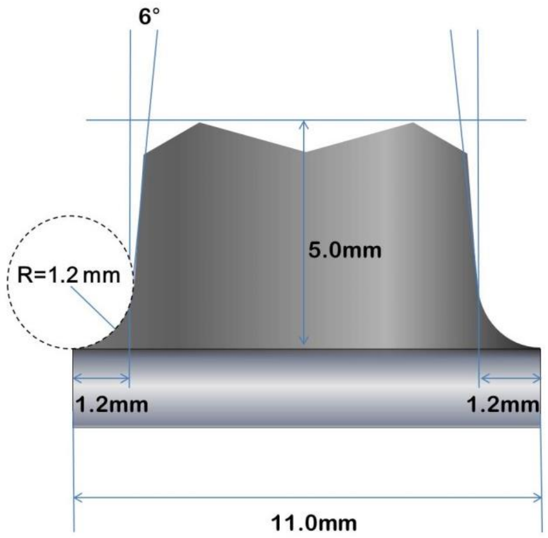
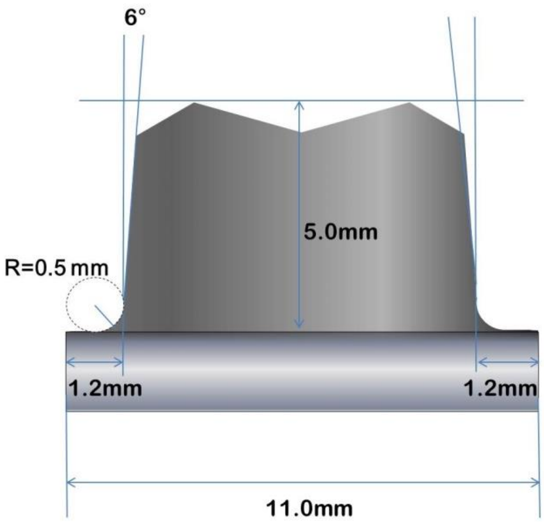


Fig. 2. Titanium master model produced based on the 3D design. (A): Deep chamfer margin. (B): Rounded shoulder margin.



(A)



(B)

Fig. 3. The dimensional design of master model. (A): Deep chamfer margin with axiogingival internal line angle of 1.2mm radius. (B): Rounded shoulder margin with axiogingival internal line angle of 0.5mm radius.

Fabrication of copings

Metal copings for each model were fabricated with three different methods: (1) Selective laser sintering (SLS), (2) CAD/CAM milling and (3) digitalized casting. The workflow of coping fabrication according to the manufacturing method was shown in Fig. 4.

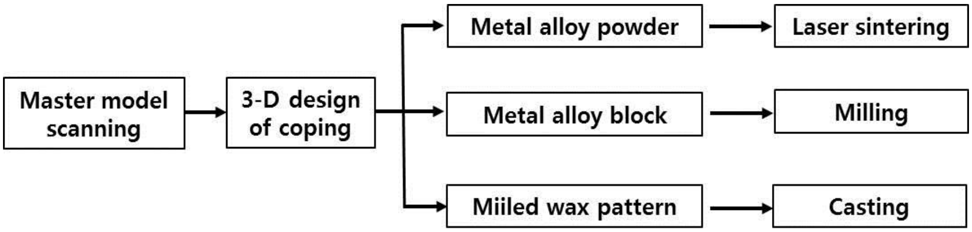


Fig. 4. The workflow of metal coping fabrication according to the manufacturing method.

(1) Selective laser sintering (SLS)

Each model was scanned by dental laser scanner (D-700, 3Shape, Copenhagen, Denmark). A skilled dental technician designed the coping using CAD software (3shape Dental Designer, 3Shape, Copenhagen, Denmark). The thickness of coping was designed to be 0.5mm (the thinnest part has 0.4mm), and the cement space was set at 35μm (the thinnest part has 25 ㎛) from 1mm above the margin (Fig. 5). This CAD data was transferred to a laser sintering machine (EOSINT M270, EOS GmbH Electro Optical Systems, Krailling, Germany) for fabricating metal frameworks. The laser sintering procedure followed the recommendation of manufacturer (EOS GmbH Electro Optical System, Krailling, Germany) and used cobalt–chromium alloy powder (Co 63.8, Cr 24.7, Mo 5.1, W 5.4, Si 1.0 ; EOS Cobalt Chrome SP2, EOS, Krailling, Germany). The fabrication was under the fixed condition ; a laser power of 200W, scan spacing of 0.1~0.2mm, a laser scan speed of 7.0 m/sec and a layer thickness of 20~30μm. All copings were sandblasted with 250 ㎛ aluminum oxide at a pressure of 3 bar before the heat treatment. The heat treatment was performed in a furnace (LAB24 SF-25, Dongseo Science Co. Ltd, Seoul, Korea) at 800 ℃ during 5 hours for releasing residual internal stress. 12 copings from the deep chamfer margin model (DS group) and 12 copings from the rounded shoulder margin model (RS group) were made respectively (Table 1).

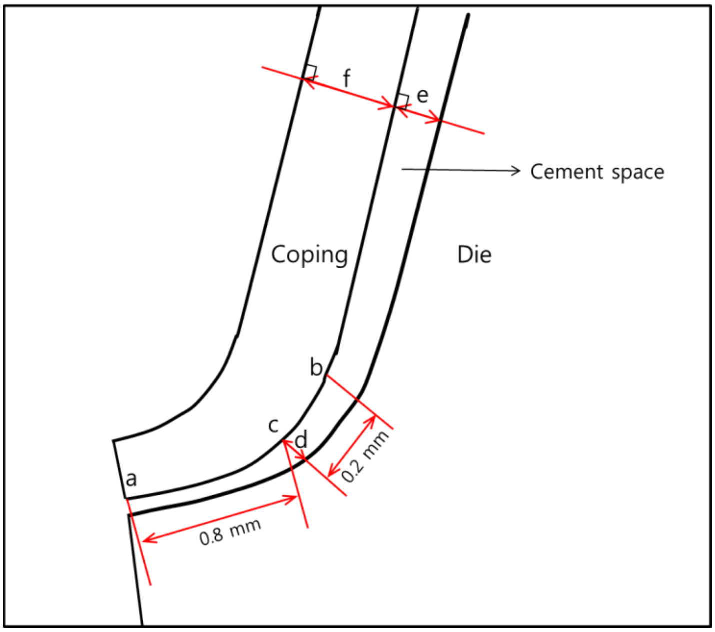


Fig. 5. The cross-sectioned image and sizes of the coping and cement space. (a) Terminal point of margin (b) Setting point of cement space; 1.0mm from terminal point. (b-c) Transition section. (d) Minimum cement space; 25μm. (e) Cement space; 35μm. (f) Thickness of coping; 0.5mm.

(2) CAD/CAM milling

The same scanning data of master models was sent to a simultaneous 5-axis milling machine (PMS5Ⅱ, Dental Plus, Kyeonggi, Korea) which has 50,000RPM/450W spindle for computerized milling. The Co-Cr alloy blocks (Co 62, Cr 30, Mo 6, Si, Mn, Fe, C ; CHROME-COBALT 95H10, Zirkonzahn, South Tyrol, Austria) were milled with milling burs (356SR, NTI, Kahla, Germany), which has 1.0mm ball size and 4° taper, according to the manufacturer’s recommendation. No treatment after fabrication was performed. 12 copings produced from the deep chamfer margin model (DM group) and 12 copings produced from the rounded shoulder margin model (RM group) were made in each group (Table 1).

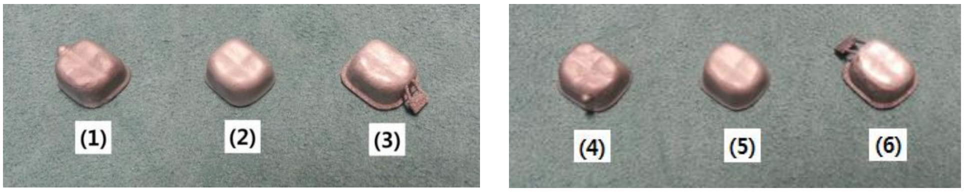
(3) Digitalized casting

To obtain the exactly same wax pattern with copings made by SLS system, the same parameters in the 3D CAD data were sent to a milling center for computerized milling (Milling Unit M5 HEAVY, Zirkonzahn, South Tyrol, Austria) of wax (Easymill Wax, High Dental Korea, Gwangju, Korea) with milling bur (CAD/CAM Bur 2L, Zirkonzahn, South Tyrol, Austria). The milled wax patterns were invested in phosphate-bonded investment material with metal ring (Vaccume furnace, Sejong Dental, Seoul, Korea), and casted with the base metal alloy (NICROMED premium, NEODONTICS, California, USA). The composition of base metal alloy used in this experiment is presented in Table 2. Casting is carried out with induction heating of 50℃ increasing temperature per minute and maximum melting temperature of 820℃, which is in combination with the centrifugal casting machine (SJ CM 01, Sejong Dental, Seoul, Korea) according to the manufacturer's instructions. No additional internal adjustment of the copings was performed except the elimination of casting nodules with rotating instruments. 12 metal copings from the deep chamfer margin model (DC group) and 12 copings casted from the shoulder margin model (RC group) were made in each group (Table 1).

Table 1. Six groups of specimens categorized by finish line design and manufacturing methods.

Manufacturing method	Deep chamfer margin	Rounded chamfer margin
Laser sintering	DS group	RS group
Milling	DM group	RM group
Casting	DC group	RC group

As each group had 12 samples, 72 samples were made in total.



(A) (B)

Fig. 6. Copings produced by three different fabricating methods from two master models. A: Deep chamfer margin group. (1) DC group. (2) DM group. (3) DS group. B: Rounded shoulder margin group. (4) RC group. (5) RM group. (6) RS group.

Table 2. Chemical composition of nonprecious alloy for fabrication of laser sintered, milled and casted metal copings as a percentage according to the manufacturer's instructions (wt %).

Alloy	Co	Ni	Cr	Mo	Si	W	Nb	Al
Laser sintering	63.8	-	24.7	5.1	1.0	5.4		
Milling	62		30	6		Etc. max. 2.0		
Casting	-	73.8	12.2	3.6	3.2		4.6	2.2

Measurements of the specimens

The marginal discrepancy was defined as the shortest distance between the margin of the preparation and the edge of the crown margin, therefore an examiner measured the perpendicular distance from a determined reference point to the edge of the metal coping in this study. Each master model has the measurement areas on mesial, buccal, distal and lingual site of the margin. Measurement area of 3000 μm were determined on each site and marked on the margin of the model. Each area has 10 reference points of P1 ~ P10 which have 300 μm distance between adjacent points. The average value of 10 measurements on a site represented the mean marginal gap of the site (Fig. 7).

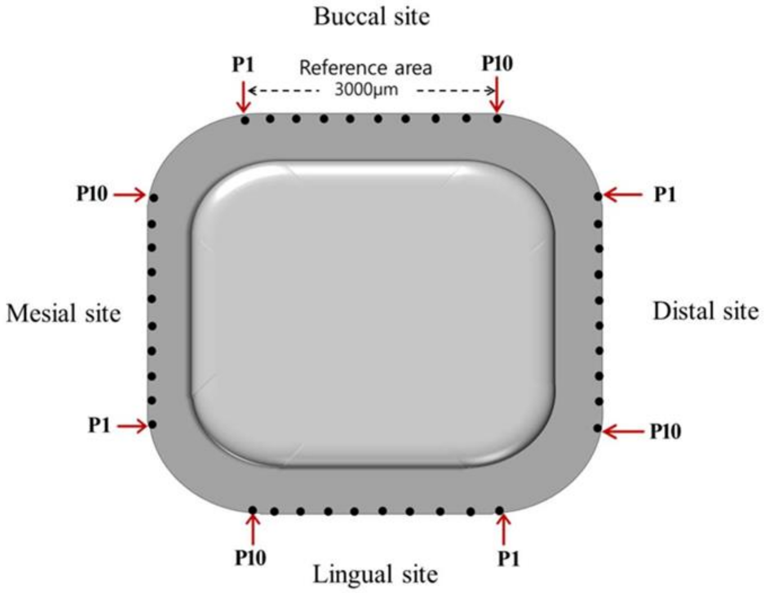


Fig. 7. Reference points on the margin of the master model. The master model has four measurement areas on the margin at mesial, buccal, distal and lingual site, respectively. Each measurement area has 10 reference points of P1 ~ P10 which have 300 μm distance between adjacent points.

A single expert examiner measured all the specimens using the confocal laser scanning microscope (CLSM) (LSM 5 PASCAL, Carl Zeiss MicroImaging GmbH, Göschwitzer, Germany) at the magnification 150. Specimens were seated to the original master die with maximum hand pressure and fixed using rubber adhesive (BluTack, Bostik, Leicester, UK). The prepared specimen was mounted onto the measuring device and the examiner controlled finely the angle of long axis of specimen at every measuring for the laser beam to bisect perpendicularly the connecting line of two determined points (Fig. 8). The distance between two points was calibrated by one experienced engineer according to the manufacturer's instructions (Fig. 9). Each specimen was measured at 40 reference points along the circumferential margin and 2880 measurements were performed on the 72 specimens in total.

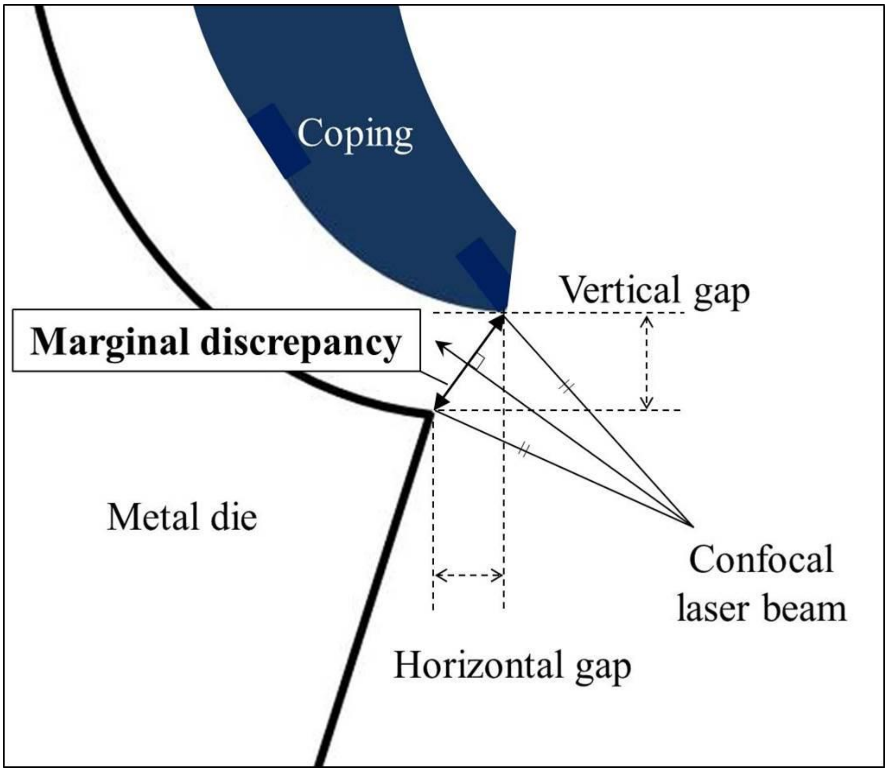


Fig. 8. Schematic section view of a specimen showing the marginal discrepancy measured in this study and the principle of measuring the distance. The marginal discrepancy is determined as the angular combination of marginal gap between the margin of the coping and the cavosurface margin(?) of the abutment. The laser beam bisects perpendicularly the connecting line of two target points.

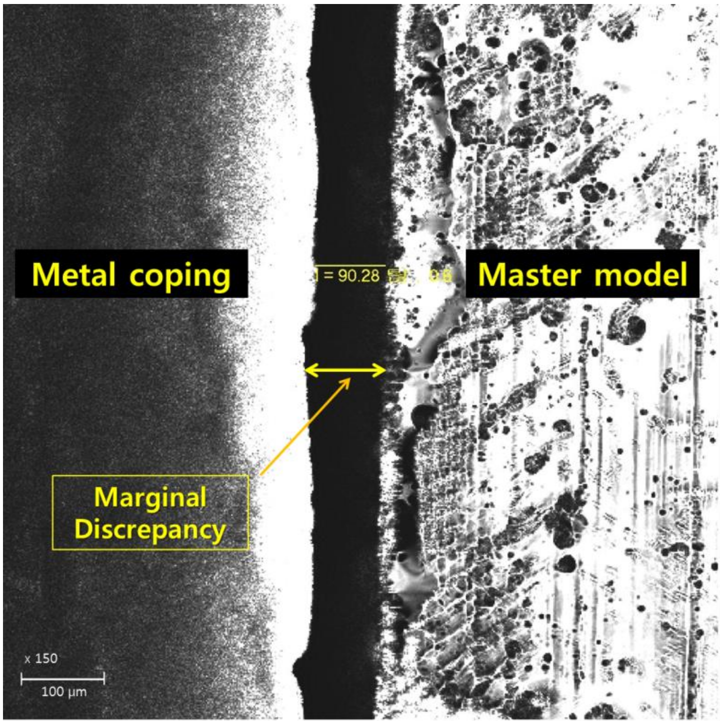


Fig. 9. Demonstration of the measurement of marginal gap by the confocal laser scanning microscope at x 150 magnification.

Statistical analysis

Shapiro-Wilk test was conducted to examine the normality of the data distribution. The normality of sample data was rejected upon the basis of the visual inspection of box plots of data distribution and the result of the supplementary Shapiro-Wilk test (p<0.05), therefore non-parametric statistics was applied to data analysis in this study.

Kruskal-Wallis Tests, which can be used whether the data follow the normal distribution or not, was conducted to evaluate the overall statistical significance of the three different manufacturing methods regarding the marginal discrepancy under two different finish lines separately.

Once statistical significance was confirmed from the overall test, Wilcoxon test was followed for multiple comparisons of each pair of three different manufacturing methods regarding the marginal gaps of the metal copings. The JMP version 11 (SAS Institute Inc., North Carolina, USA) was used for all statistical analyses at a significance level of 5%.

RESULTS

1. Deep chamfer margin

The mean values and standard deviations of the marginal discrepancies of three groups with deep chamfer margin are shown on Table 3. The distribution and median value of sample data was shown in Fig. 10. SLS group showed the best marginal fit among three groups at mesial, labial, lingual site and casting group had better marginal fit than other groups at distal site. The mean average marginal gaps are significantly different among the three different fabricating methods at every site (p<.05) (Table 3).

SLS group had the smallest mean marginal discrepancy and standard deviation at all position into one. The value was 11.8±7.4 μm, which was smaller than 18.8±20.2 μm of casting group and 53.9±27.8 μm of milling group. SLS group had more homogeneous marginal gap than other groups and the differences among the three groups were statistically significant in total (p<.0001).

Table 3. Mean (SD) value of absolute marginal discrepancy for four sites of the metal copings with deep chamfer margin by Kruskal-Wallis Tests (unit: μm)

Site	SLS DS group	Milling DM group	Casting DC group	*p*-value
Mesial	17.8(8.8)	45.2(20.2)	45(26)	0.0073
Labial	6.8(1.5)	61.4(34.9)	16(5.3)	<.0001
Distal	16.8(5.1)	32.2(17.7)	7.6(1.6)	<.0001
Lingual	5.9(1.3)	76.7(13)	6.4(2)	<.0001
Total	11.8(7.4)	53.9(27.8)	18.8(20.2)	<.0001

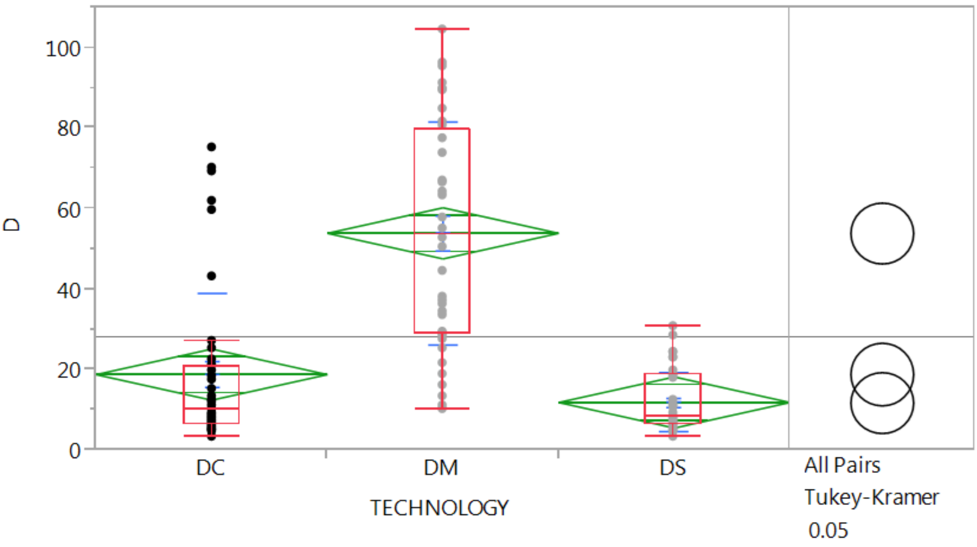


Fig. 10. Box plots of population distribution and mean value of the marginal discrepancy of Co-Cr copings with deep chamfer margin according to the manufacturing methods. Line in each box represents median value of each group. The diagram showed that the data of marginal gap were not normally distributed (α=.05).

Based on the above result, multiple comparisons for each pair of three manufacturing methods were performed additionally and the results were shown in Table 4. The 9 pairs of total 12 pairs represented statistical significance and only labial site represented the significant differences about all of the three comparisons (Table 4).

Table 4. Comparison of the mean marginal discrepancy of three manufacturing methods at each site (DC: casting, DM: milling, DS: selective laser sintering)

Site	Comparison	*p*-Value
Mesial	DM >[§] DC	1.0000
	DS < DC	0.0257*
	DS < DM	0.0022*
Labial	DM > DC	0.0006*
	DS < DC	0.0002*
	DS < DM	0.0002*
Distal	DS > DC	0.0002*
	DM > DC	0.0002*
	DS < DM	0.0640
Lingual	DM > DC	0.0002*
	DS < DC	0.5708
	DS < DM	0.0002*

[§] A sign of inequality means the result of the comparison of the mean marginal gap values of two groups, therefore the smaller means the better marginal fit.

* The mean difference is statistically significant at the level of .05.

2. Rounded shoulder margin

The mean values and standard deviations of the marginal gap of the metal copings with rounded shoulder margin are shown on Table 5. The distribution and median value of sample data was shown in Fig. 11. The result revealed that the marginal gaps are significantly different among the three different fabricating methods at mesial, buccal, distal and lingual site. SLS group showed the best marginal fit among three groups at every site (p<.05).

The mean average marginal gap distance was 6.3±3.5 μm in laser sintering group, 48.6±30.1 μm in milling group and 33±20.5 μm in casting group regarding the total circumferential margin. The result was also same as deep chamfer margin in that laser sintered copings showed the smallest mean marginal gap and homogeneous marginal gap. Casting and milling method followed that in order (p<.0001) (Table 5).

Table 5. Mean (SD) value of absolute marginal discrepancy for four sites of the metal copings with rounded shoulder margin by Kruskal-Wallis Tests (unit: μm)

Site	SLS (RS group)	Milling (RM group)	Casting (RC group)	*p*-value
Mesial	8.1(1.7)	44.6(38)	43.9(13.6)	0.0005
Labial	9.1(5)	63.7(36.7)	49.8(18)	<.0001
Distal	4.3(1.1)	51.1(19.4)	28.1(15.5)	<.0001
Lingual	3.6(1)	35.1(17.8)	10.3(4.5)	<.0001
Total	6.3(3.5)	48.6(30.1)	33(20.5)	<.0001

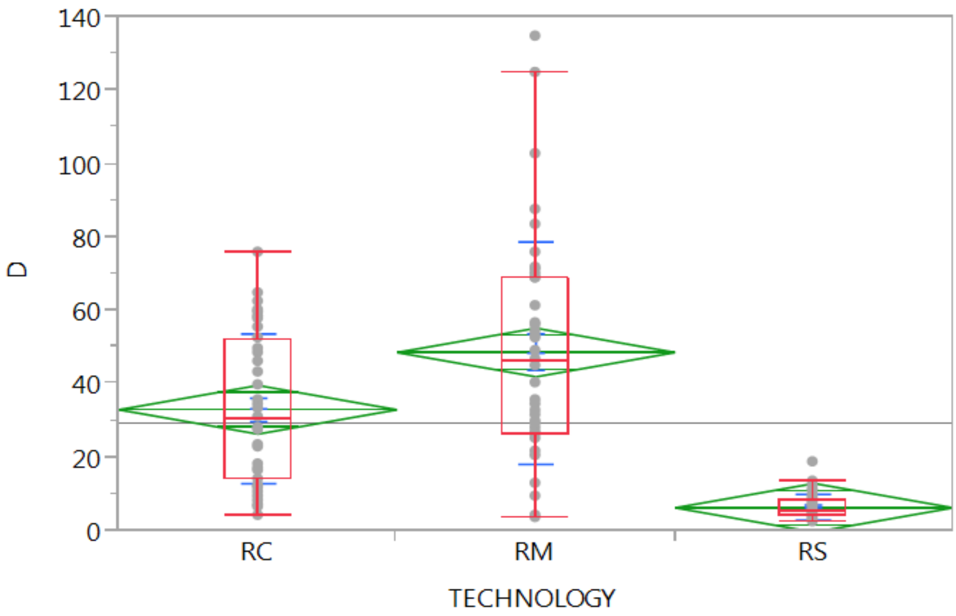


Fig. 11. Box plots of population distribution and mean value of the marginal discrepancy of Co-Cr copings with rounded shoulder margin according to the manufacturing methods. Line in each box represents median value of each group. The diagram showed that the data of marginal gap were not normally distributed (α=.05).

Based on the above result, multiple comparisons for each pair of three manufacturing methods were performed additionally and the results were shown in Table 6. The 10 pairs of total 12 pairs represented statistical significance and distal and lingual site represented the significant differences about all of the three comparisons (Table 6).

Table 6. Comparison of three manufacturing methods regarding the marginal discrepancy at each site in rounded shoulder margin group (RC: casting, RM: milling, RS: selective laser sintering)

Site	Comparison	*p*-Value
Mesial	RM >[§] RC	0.5205
	RS < RC	0.0058*
	RS < RM	0.0002*
Labial	RM > RC	0.4727
	RS < RC	0.0002*
	RS < RM	0.0002*
Distal	RS < RC	0.0257*
	RM > RC	0.0002*
	RS < RM	0.0002*
Lingual	RM > RC	0.0058*
	RS < RC	0.0008*
	RS < RM	0.0004*

[§] A sign of inequality means the result of the comparison of the mean marginal gap values of two groups, therefore the smaller means the better marginal fit.

* The mean difference is significant at the level of .05. The mean marginal discrepancy of sintered copings was smaller than those of casted and milled copings at all marginal sites.

3. Comparison of two different finish line design regard to marginal gap

The comparison of the mean marginal discrepancy of nonprecious alloy copings with two different margins was conducted regard to the same manufacturing method. The difference of marginal gap between deep chamfer margin and rounded shoulder margin was compared at each site and in total.

3.1 DS vs RS (laser sintered copings)

The average marginal gaps of laser sintered copings are shown by part in table 7. Deep chamfer margin represent larger gap than rounded shoulder margin at mesial, distal and lingual site and the differences were statistically significant (p<.05). The opposite result was shown at labial site and the difference was not statistically significant (p=0.5453). Meanwhile, lingual site had the best marginal fit among all site in both of two marginal designs (5.9±1.3 μm for deep chamfer margin and 3.6±1 μm for rounded shoulder margin). According to total mean values of all site into one, deep chamfer margin (11.8±7.4 μm) exhibited significantly greater marginal discrepancy than rounded shoulder margin (6.3±3.5 μm) (p<.0001)

Table 7. Comparison of absolute marginal gap between two different finish lines of laser sintered copings (DS vs RS).

Site	Deep chamfer margin	Rounded shoulder margin	*p*-Value
Mesial	17.8(8.8)	8.1(1.7)	0.0140*
Labial	6.8(1.5)	9.1(5)	0.5453
Distal	16.8(5.1)	4.3(1.1)	0.0002*
Lingual	5.9(1.3)	3.6(1)	0.0015*
Total	11.8(7.4)	6.3(3.5)	<.0001*

3.2 DM vs RM (milled copings)

The average marginal gaps of milled copings are shown by part in table 8. Deep chamfer margin represented smaller gap than rounded shoulder margin at mesial site (*p*=0.5967) and deep chamfer margin represented larger gap than rounded shoulder margin at labial site (*p*= 0.8798), however those differences were not statistically significant (Table 8). Deep chamfer margin showed smaller gap than rounded shoulder margin at mesial site (*p*=0.0413) and deep chamfer margin showed greater gap than rounded shoulder margin at labial site (*p*=0.0002) resulting in statistically significant differences. Meanwhile, distal site had the best marginal fit among all site in deep chamfer design (32.2±17.7 μm) , whereas lingual site had the best marginal fit among all site in rounded shoulder design (35.1±17.8 μm). In total mean values, the difference between deep chamfer margin (53.9±27.8 μm) and rounded shoulder margin (48.6±30.1 μm) was not statistically significant (*p*=0.279) (Table 8).

Table 8. Comparison of absolute marginal gap between two different finish lines of milled copings (DM vs RM).

Site	Deep chamfer margin	Rounded shoulder margin	*p*-Value
Mesial	45.2(20.2)	44.6(38)	0.5967
Labial	61.4(34.9)	63.7(36.7)	0.8798
Distal	32.2(17.7)	51.1(19.4)	0.0413*
Lingual	76.7(13)	35.1(17.8)	0.0002**
Total	53.9(27.8)	48.6(30.1)	0.2790

3.3 DC vs RC (digitalized casting)

The average marginal gaps of digitalized casted copings are shown by part in table 9. Deep chamfer margin represented smaller gap than rounded shoulder margin at all site except mesial site. The differences between two marginal finish lines according to the marginal gap were statistically significant at labial site (*p*= 0.0004) and distal site (*p*=0.0003) (Table 9). According to total mean values of all site into one, deep chamfer margin (18.8±20.2 μm) exhibited significantly greater marginal discrepancy than rounded shoulder margin (33±20.5 μm) (*p*=.0004)(Table 9).

Table 9. Comparison of absolute marginal gap between two different finish lines of digitalized casted copings (DC vs RC).

Site	**Deep chamfer margin**	**Rounded shoulder margin**	***p*-Value**
Mesial	45(26)	43.9(13.6)	0.8206
Labial	16(5.3)	49.8(18)	0.0004*
Distal	7.6(1.6)	28.1(15.5)	0.0003*
Lingual	6.4(2)	10.3(4.5)	0.0696
Total	18.8(20.2)	33(20.5)	0.0004*

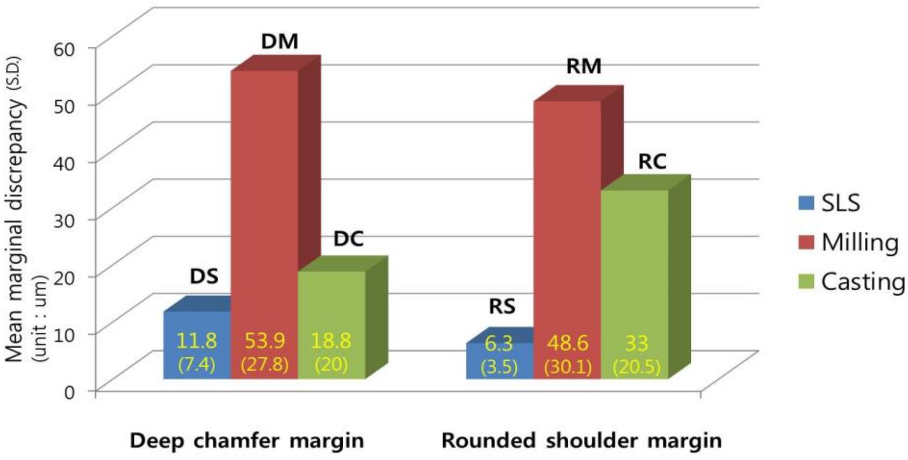


Fig. 12. Comparison of mean marginal gap between groups fabricated by different methods. The difference of the marginal fit among three methods was statistically significant for both finish line designs. The laser sintered copings showed the narrowest marginal gap among three groups regardless of marginal design. The milled copings showed the widest marginal gap among three groups regardless of marginal design.

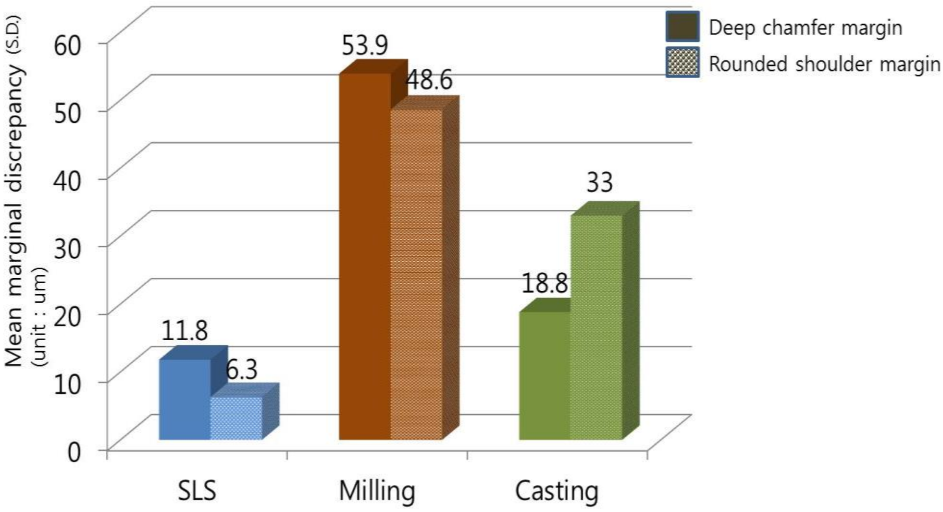


Fig. 13. Comparison of mean marginal gap between two different finish lines. Rounded shoulder margin has better fit than deep chamfer margin in SLS group and milling group, while the opposite result was shown in casting group. The differences were statistically significant in SLS group (p<.0001) and casting group (p=.0004).

DISCUSSION

The present study was conducted to evaluate the influence of finish line design on the marginal fit of nonprecious metal alloy coping. With this view, metal copings manufactured by three different methods – selective laser sintering, milling and digitalized casting - were compared regard to the marginal discrepancy. From the analysis of the data, the first null hypothesis was rejected that the finish line design do not influence the marginal gap of nonprecious metal alloy coping, and the second null hypothesis was rejected that the marginal fit of laser sintered metal alloy coping was similar to that of casted coping and milled coping.

This study tried to simulate the prepared abutment of human tooth as master models. For that, a resin tooth was prepared first, which has the average size and shape of human tooth, and then a design of master model was implemented based on the outline of prepared resin tooth. This procedure is needed because the human tooth is not like cylinder shape and the appearance of occlusal surface is not flat. There are some studies with similar concept to this study, however they used a simplified master model or a prepared ivory tooth or a particular tooth of human.[40-43] As the authors verified ahead that the accuracy of the abutment preparation influenced the quality of marginal fit in previous study,[49] the master models of this study simulated the abutment from the average human tooth and the preparation procedure was substituted to computer designing of master model.

The procedure explained above could be possible with three-dimensional designing work using computer program (3D CAD, Dassault Systemes SOLIDWORKS Corp., Waltham, MA, USA). 3D CAD is the world’s most popular computer designing software which utilizes a parametric feature-based approach to create models. The designing program consists of geometry such as points, lines, arcs, conics and splines, and implements relations such as tangency, parallelism, perpendicularity and concentricity. That means a possibility of building a model corresponding with the principle of abutment preparation. Therefore, the models of present study have smooth finish line at all around the margin, regular radius of the axiogingival internal line angle and steady axial wall taper circumferentially. This point makes this study meaningful in that inter-experimenter variability was excluded. This is because that the authors assured the fact in the previous study that the hand preparation revealed the irregular wave of running of the finish line and inconsistency of axial wall taper and radius, which may affect the clinical results.[49]

The marginal discrepancies of metal copings regard to the finish line design were significantly different in SLS group and casting group (Table 7, 9). Copings with rounded shoulder margin showed better marginal fit than deep chamfer margin in SLS group, whereas the opposite result was shown in casting group. The curvature radius of the axiogingival internal line angle may affect the marginal adaptation of copings. The rounded shoulder margin design has smaller curvature radius than that of deep chamfer margin. SLS technique showed the highest accuracy among three manufacturing methods (Fig. 10) and that means it has more excellent ability to interpret fine design than other methods. Meanwhile, there was no significant difference between two finish lines in milling group which has the largest average marginal gap (Table 8) (Fig. 10). The relatively inferior accuracy of milling method may be a limitation to reflect the fine difference of the design between the two finish lines.

For the comparison of manufacturing method, the analysis showed significantly different mean marginal discrepancies among three methods (Table 3, 5). Multiple comparisons among them revealed that the marginal fit was good in order of SLS, casting and milling regardless of finish line design (Table 3, 5) (Fig. 10). The findings of many other studies are in agreement with the results of the current study,[44-48] although Kim et al. reported that the marginal gap measured in SLS group was greater than that of casting group.[42,43] The excellent marginal fit of laser sintered coping was explained in that the fabricating process is simplified and do not need tools such as milling bur. Moreover, compared with conventional lost wax technique which consists of many procedures, the SLS technique eliminates the inter-operator variation and is almost without porosity.[19,50] The reason of the largest marginal gap in milling group may be explained that it is more difficult to mill the metal alloy block precisely due to its hardness. The resistance of the milling axis and its vibration could affect the delicate procedure, compared with the milling of the soft pattern wax used in digitalized casting method. Moreover, wear of milling bur reduces the cutting efficiency and fineness, which reduce the consistency of the accuracy. These factors may cause the large standard deviation of data in both milling group and casting group, which consists of milling procedure in common. That was contrast to the small standard deviation of laser sintered copings.

According to the marginal gap for each site, five groups among six groups, only except DM group, exhibited the best marginal fit on lingual site (Table 3, 5). The outline of lingual margin of abutment model simulating mandibular first molar is almost like straight line compared with the other sites. The more complex design induces the more probability of occurrence of errors. Meanwhile, there was no consistency regard to the site of the most inferior marginal fit in DS, DM and DC group. On the other hand, average marginal fit of labial site was the worst in RS, RM and RC groups in common (Table 3, 5). It may be due to the volume and the height of buccal cusps of rounded shoulder margin model, because the larger volume of material occurs the more amount of contraction and the length from the buccal cusp tip to the labial margin is longer and more curved than the length from lingual cusp tip to the lingual margin.

Many studies about the marginal fit of various crowns have been reported, however it is difficult to compare the studies directly because there are many concepts regard to the marginal discrepancy.[18] Marginal gap is the shortest distance from the coping to the die surface. Horizontal marginal gap is the horizontal marginal misfit measured perpendicular to the path of draw of the coping and vertical marginal gap is the vertical marginal misfit measured parallel to the path of draw of the coping. Absolute marginal discrepancy means the distance measured from the margin of the coping to the cavosurface angle of the die as the angular combination of the marginal gap.[51] In this study, the absolute marginal discrepancy was determined as the representation of marginal fit, because the other concepts mentioned above are not the real distance but visual distance (Fig. 6). Moreover, vertical marginal gap cannot be measured if the margin of coping hangs over the prepared margin of the abutment, however the absolute marginal discrepancy is available in case of the over-hanging margin.

The marginal fit was assessed by measuring the shortest distance from the determined reference points to the edge of coping with a confocal laser scanning microscope (CLSM) in this study. CLSMs can measure the exact absolute marginal discrepancy, because the apparatus can focus two objects at the same time only when the distances between the laser beam source and the objects are same. That means the laser beam bisects the connecting line between two points perpendicular (Fig. 6). However, the limitation of this method is that it cannot be used for measuring of internal gap. Many other studies used replica technique which is the method of measuring the thickness of the intervention between abutment and the coping.[52,53] Disadvantage of this method is the low reliability of the value by sectioning of the specimen. The small number of measurement point and the ambiguous boundary of intervention material on the microscopic view are the serious limitation of replica technique.[43]

In this study, the values of the marginal gap was smaller than those of other studies in general. örtorp et al.[48] presented the mean cement film thickness of 84㎛ on 3-unit fixed prostheses. Kim et al. reported the marginal gap of 75.0㎛ measured with the intervention of light body silicone for replica Technique.[43] Castillo-Oyague et al. reported the range of 27.2~61.6㎛ for misfit of implant supported crown coping obtained by laser sintering luted with several kind of agents.[46] The main reason of that the values of marginal gap in this study was somewhat smaller than other studies is no intervention of material between coping and model. The intervention of a luting material hinder the coping from sitting on the abutment fully and the viscosity and flowability of many various cement materials effect differently on it.[44,46,47] Another reason can be that the occlusal surface of master model followed anatomic preparation. Syed et al. reported that anatomical occlusal preparation designs resulted in better marginal and internal adaptation of Zr copings than non-anatomical occlusal design.[54] In addition, master model fabrication was based on the computer design which makes the procedure more accurate than hand preparation.[49]

Several studies about SLS technology compared laser sintered Co-Cr alloy and casted Co-Cr alloy, because Co-Cr alloy is the only nonprecious metal alloy that

SLS technic handles at present. The results suggested that the marginal distortion during the casting of Co-Cr alloy may be overcome through the use of SLS method.[16,17,45,48] Meanwhile, some other studies were conducted with various materials. Quante et al. compared the marginal and internal fit between SLS Co-Cr crown and SLS Au-Pt crown, and resulted comparable marginal fit between the two alloys.[15] Ucar et al. evaluated the internal fit of SLS Co-Cr crown, casted Co-Cr crown and casted Ni-Cr crown, and the result of difference was not statically significant (p=.42).[7] Castillo-Oyagüe et al. assessed misfit of implant supported crown and three-unit bridge, and they reported SLS crown has the best fit and cast Co-Cr performed equally well to cast Ni-Cr crown.[46,47] Sundar et al. reported that the marginal fit of SLS Co-Cr coping has better marginal fit than cast Ni-Cr coping.[44] This result is same as the result of present study, however the producing method of casted Ni-Cr coping was different. Sundar's Ni-Cr coping was fabricated by conventional lost wax technique, while this study used the same computerized design of coping with SLS coping and milled wax pattern by CAD/CAM. This point is meaningful because the consistency of the thickness of coping and cement space influence the accuracy of fit. Soriani et al. studied the effect of thickness of die spacer on the marginal fit of copings and concluded that there was a statistically significant difference ($p<0.05$) according to the various thickness of die spacer.[55]

In this study, the abutment preparations were digitalized and one professional examiner performed the measurement of the specimens so that the performance bias and inter-examiner variability did not occur. For future study, the comparison of the marginal adaptation of the metal coping between before and after of porcelain firing could be considered and the new experimental design to measure both marginal and internal gap are required.

CONCLUSION

Within the limitation of this study, the following conclusions were drawn : The variation of finish line design influenced the marginal adaptation of laser sintered metal coping and casted metal coping. Rounded shoulder margin shows better fit than deep chamfer margin in laser sintered coping, while deep chamfer margin has better marginal fit than rounded shoulder margin in casted copings, and the differences were statistically significant in both methods. Milled copings with rounded shoulder margin shows better fit than deep chamfer margin, but no significant difference of the marginal adaptation was found between those two margin designs. In addition, the marginal fit of base metal coping differed depending on the site of the margin. Especially, there was a tendency that the lingual margin has the better marginal fit than other sites in rounded shoulder margin groups.

According to the manufacturing method, SLS system showed the best marginal adaptation of base metal coping in comparison with milling and casting method and it implemented homogeneous margin. On the contrary, milling method showed relatively inferior marginal accuracy than SLS system or digitalized casting method and exhibited low ability to implement the difference of finish line designs. Based on the findings of the present study, it may be recommended to choose the adequate manufacturing method of metal coping depending on the finish line design in the clinical aspect.

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국문초록

CAD/CAM 을 활용하여 3D printing, milling, casting 방법으로 제작한 비귀금속 합금 코핑의 지대치 변연 형태에 따른 변연 적합도의 변화

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김 서 랑

연구 목적 : 본 연구의 목적은 레이저 신터링, 컴퓨터 밀링, 주조의 세 가지 방법으로 제작된 비귀금속 합금 코핑의 변연 형태에 따른 변연 적합도의 변화를 관찰하는 데 있다. 이를 위해서, 각각 deep chamfer margin 과 rounded shoulder margin 을 가지는 두 모델을 제작하고, 위의 두 가지의 변연에 대하여 제작방식 간에 적합도의 차이도 비교해보고자 하였다.

재료 및 방법: 서로 다른 두 개의 변연 형태를 정확히 재현하기 위해 3D CAD 를 이용하여 지대치 삭제의 원칙에 따라 지대치를 디자인한 다음, 티타늄 블럭을 컴퓨터 밀링하여 주모델을 제작하였다. 각각의 모델에 대하여 위의 3 가지 제작 방법으로 비귀금속 합금 코핑을 12 개씩 제작하여, 총 72 개의 코핑을 제작하였다. 각 코핑은 지대치에 적합시켜서 공초점 레이저 주사 현미경으로 근심, 협측, 원심, 설측 변연의 변연 적합도를 150 배율로 측정하였다.

결과: 레이저 신터링으로 제작한 코핑의 평균 변연 격차는 deep chamfer margin 에서 11.8±7.4 µm, rounded shoulder margin 에서 6.3±3.5 µm 였고, 그 차이는 통계적으로 유의했다 (p<.0001). 컴퓨터 밀링으로 제작한 그룹에서는 deep chamfer margin 에서 53.9±27.8µm, rounded shoulder margin 에서 48.6±30.0 µm 였고, 변연 형태에 따른 유의한 차이가 없었다 (p=.279). 주조 방법으로 제작한 그룹은 deep chamfer margin 에서 18.8±20.2 µm, rounded shoulder margin 에서 30±20.5 µm 였고, 그 차이는 통계적으로 유의했다 (p=.0004). 한 편, 같은 변연 형태에 대한 세 가지 제작 방식 간의 정밀도 차이는 두 종류의 변연 형태에서 모두 유의하게 나타났는데, 레이저 신터링 방법이 가장 우수하였고, 다음으로 주조와 밀링의 순으로 변연 적합도가 양호하였다.

결론 : 이번 실험을 통하여, 다음과 같은 결론을 얻었다.

1. 변연의 형태에 따른 변연 적합도는 레이저 신터링이나 주조 방법으로 제작된 금속 코핑의 경우 변연 형태에 따라 유의한 차이가 있었다.

2. 레이저 신터링으로 제작한 금속 코핑에서 rounded shoulder margin 이 deep chamfer margin 보다 우수한 변연 적합도를 보였다.

3. 주조 방법으로 제작한 금속 코핑의 경우는 deep chamfer margin 이 rounded shoulder margin 보다 우수한 변연 적합도를 보였다

4. 밀링 방법으로 제작된 금속 코핑은 마진 형태에 따라 변연 적합도가 유의하게 달라지지 않았다.

5. 제작 방식에 따른 코핑의 변연 적합도는 레이저 신터링이 가장 양호하였고, 그 다음 주조 방법과 밀링 방법 순으로 변연 적합도가 양호하였다.

이번 연구를 통해, 지대치의 변연 형태에 따른 금속 코핑의 변연 적합도의 변화를 관찰하였으며, 레이저 신터링으로 제작하거나 디지털 밀링한 왁스 패턴을 캐스팅한 경우에는 상관 관계가 있음을 확인하였다. 임상에 적용함에 있어 지대치의 변연 형태를 고려하여 금속 코핑의 제작 방법을 결정하는 것이 추천된다.

주요어; CAD/CAM , 3D printing, 레이저 신터링, 비귀금속 합금 코핑, 변연적합도

학 번 : 2013-30629

치의학박사학위논문

Influence of finish line design on the marginal fit of nonprecious metal alloy coping fabricated by 3D printing, milling and casting using CAD/CAM

CAD/CAM 을 활용하여 3D printing, milling, casting 방법으로 제작한 비귀금속 합금 코핑의 지대치 변연 형태에 따른 변연 적합도의 변화

2016 년 2 월

서울대학교 대학원

치의과학과 치과보철학 전공

김 서 랑

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지도교수 곽 재 영

이 논문을 치의학박사 학위논문으로 제출함

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김 서 랑

김 서 랑의 박사학위논문을 인준함

2015년 12월

위 원 장 ________________ **(인)**

부위원장 ________________ **(인)**

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ABSTRACT

Influence of finish line design on the marginal fit of nonprecious metal alloy coping fabricated by 3D printing, milling and casting using CAD/CAM

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Purpose: The purpose of this study was to examine the correlation between the finish line designs and the marginal adaptation of nonprecious metal alloy coping produced by different digital manufacturing methods. With this view, one master model with deep chamfer margin and another master model with rounded shoulder margin were fabricated and this study was aimed to compare the correlation depending on the three different manufacturing methods of selective laser sintering, milling and casting.

Materials and methods: For fabrication of two master models with different finish lines, the master models were designed by 3-D designing software program based on the abutment preparation principle and titanium master models were milled by computer aided manufacturing. Nonprecious metal alloy copings were made respectively from each master model with three different methods; selective laser sintering (SLS), milling and casting by CAD/CAM. 12 copings were made by each method resulting in 72 copings in total. The marginal fit was evaluated by measuring the gap between the cavosurface margin of the abutment die and the edge of the crown margin on mesial, buccal, distal and lingual site of each specimen. The measurement was conducted at 40 determined reference points along the circumferential margin with the confocal laser scanning microscope at magnification x150.

Results: Mean values of marginal gap of laser sintered copings were 11.8±7.4 μm for deep chamfer margin and 6.3±3.5 μm for rounded shoulder margin and the difference between them was statistically significant ($p<.0001$). Mean values of marginal gap of milled copings were 53.9±27.8 μm for deep chamfer margin and 48.6±30.1 μm for rounded shoulder margin and the difference between them was not significant ($p=.279$). Mean values of marginal gap of casted copings were 18.8±20.2μm for deep chamfer margin and 33±20.5 μm for rounded shoulder margin and the difference between them was significant ($p=.0004$). Meanwhile, the marginal fit depending on the manufacturing method was significantly different regardless of finish line design. Selective laser sintering group exhibited the best marginal adaptation among three manufacturing methods and digitalized casting group showed better marginal fit than milling group.

Conclusion: Within the limitation of this study, the following conclusions were drawn.

1. The variation of finish line design influences the marginal fit of laser sintered metal coping and casted metal coping.

2. Laser sintered copings with rounded shoulder margin had better marginal fit than deep chamfer margin.

3. Casted copings with deep chamfer margin had better marginal fit than rounded shoulder margin.

4. No significant difference on the marginal fit was found between deep chamfer margin and rounded shoulder margin in milled metal coping.

5. According to the manufacturing method, SLS system showed the best marginal fit among three different methods. Casting and milling method followed that in order.

Key words : CAD/CAM , 3D printing, selective laser sintering, nonprecious alloy coping , marginal fit

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CONTENTS

INTRODUCTION

The use of nonprecious metal alloys as dental materials is increasing owing to the expensive cost of precious metal alloy. The most widely used base metal alloys are Cobalt-Chrome (Co-Cr) alloy and Nickel-Chrome (Ni-Cr) alloy. Co-Cr alloy has been generally used for metal framework of removable partial denture, as the material is rigid enough for the intraoral functioning, resistant to corrosion, less allergenic than Ni-Cr alloy and more economic compared with noble metal alloys.[1-3] However, certain properties of it such as high melting range, low ductility[4,5] and Chrome oxide layer of surface[6,7] make the casting process of it difficult and generate errors. In comparison, Ni-Cr alloy has been used for metal coping of porcelain fused to metal crown as a substitute of precious alloy, because it has higher bond strength to porcelain than Co-Cr alloy and a similar thermal expansion to gold alloy and higher strength than precious metal alloy for long span prostheses.

The traditional lost wax casting has been the most common method of fabricating metal alloy for many decades,[8] but errors accumulate in the series of laboratory steps including the expansion and contraction of the impression materials, gypsum, wax, investment, and alloy. These accumulated errors result in the inaccuracy of the prostheses consequentially.[9]

Meanwhile, as digital dentistry has been advanced rapidly, many parts of the dental works can be digitalized such as intraoral digital impression, producing stereolithographic model, virtual articulation and computer-aided design/computer-assisted manufacturing (CAD/CAM) of prosthesis. Especially, CAD/CAM system has been developed a lot and becomes more popular for recent decades.[10] It was to reduce the error occurring in the manual laboratory steps.[11] CAD/CAM milling is a subtractive method of milling block-shaped materials with diamond rotary instruments. The advantage of this method is time saving because multiple producing is possible at the same time and it simplifies many steps of conventional procedure,[12] whereas the waste of materials and the wear of milling burs can be its disadvantages.

There are numerous CAD/CAM systems for the scanning and the corresponding milling procedures used in different dental applications. The Procera® system (Nobel Biocare AB, Göteborg, Sweden) introduced in 1991 was developed for manufacturing individualized dental restorations with networked CAD/CAM systems. CEREC® system (Sirona Dental System LLC, Blenheim, Germany) was also introduced for chair side use as a compact machine set.[7] Following them, Pro 50® system (Cynonad Inc., Montreal, Canada), DCS Dental® (DCS Dental AG, Allschwil, Switzerland), Everest® (Kavo Dental GmbH, Biberach, Germany), Cercon smart ceramics® system (DeguDent GmbH, Hanau, Germany), and LAVA® system (3M ESPE Dental AG, St. Paul, MN, USA) etc. have been introduced and mainly utilized for diverse dental applications.[12] Nevertheless, accurate digitalization of the information and industrial manufacturing of restorations remain challenging and require continuous quality assessments.[11,13,14]

In comparison with the milling method, selective laser sintering (SLS) is recently introduced as a manufacturing technology in dentistry. SLS is one of the rapid prototyping production methods, which fuses metal powder on to a solid part by melting it selectively using the focused laser beam and adds up layer by layer based on the CAD data.[5] This new technology has been used to produce substructures for metal ceramic crown and partial fixed dental prosthesis from Co-Cr base alloys and Au-Pt noble alloys [15-17] and also applied to make dental models out of pigmented polyamide powder. It is contrast to the milling technique in that it is basically an additive method and has no limitation of designing 3-D shapes with complex geometry.[18] Furthermore, the SLM metal copings have been reported to have satisfactory mechanical and chemical properties.[19-22] Nevertheless, this method is not popular owing to the expensive cost of the apparatus yet and the application of more various dental materials is needed.

There are several laser sintering systems being applied to dentistry at present; EOSINT M270 (EOS GmbH – Electro Optical Systems, Krailling, Germany),[5,23,24] FORMIGA P110 (EOS GmbH – Electro Optical Systems, Krailling, Germany), ProX 100 Dental (3D Systems, South Carolina, USA), EnvisionTEC 3Dent (EnvisionTEC® , Marl, Germany), AM250 (Renishaw plc, Gloucestershire, UK), PM 100 Dental System (PHENIX Systems, Clermont-Ferrand, France),[2,6,15] and BEGO MEDIFACTURING System (BEGO Medical, Bremen, Germany).[2,25] PM 100 Dental System (PHENIX Systems, Clermont-Ferrand, France) is the first manufacturing system using laser melting technique of cobalt-chromium powder for dental laboratory fabrication of prostheses.[2] EOSINT M270 (EOS GmbH – Electro Optical Systems, Krailling, Germany) is the first known dental laser sintering apparatus in Korea and was used in this study.

The marginal fit is one of the key factors for the clinical success of dental restorations.[26-29] Ideal marginal adaptation can reduce gingival irritation[30] and cement dissolution.[31] After clinically examining over 1000 metal ceramic crowns, McLean and von Fraunhofer[32] reported that marginal discrepancies up to 120 μm were acceptable. Other clinicians considered a marginal fit of 100 μm to be clinically acceptable for the longevity of the restorations.[33,34]

Regard to the factors affecting to the marginal adaptation, some studies have shown that the marginal adaptation of metal-ceramic crowns is influenced by the type of finish line.[35-37] Omar reported that the marginal adaptation of a shoulder-bevel metal-ceramic crown was significantly better than that of a metal-ceramic crown with a 90-degree shoulder.[37] However, other authors have reported that the marginal design or finish line design had no influence on the marginal adaptation of metal-ceramic crowns.[38,39] Meanwhile, there are several studies about the influence of finish line design on the marginal adaptation of gold crown. Gavelis et al. studied the effect of seven finish lines on the marginal seal and reported 41μm of shoulder margin and 44μm of chamfer margin for gold crown.[40] Shiratsuchi et al. concluded that the marginal adaptation of electroformed gold copings was significantly affected by the finish line design and suggested that a deep chamfer and a rounded shoulder design facilitate marginal adaptation in comparison to a shoulder design and may be preferred for metal ceramic crowns.[41] Based on these results, this in vitro study chose rounded shoulder margin and deep chamfer margin appropriate for anterior and posterior tooth preparation.

Many studies about the clinical acceptability of SLS technique have been conducted so far, particularly regard to the accuracy of the marginal adaptation. Quante et al. reported that no statistically significant differences between base metal alloy and precious alloy according to the marginal and internal fit of copings produced with laser melting technology was found.[15] Kim et al. concluded that no significant difference was found between the measurements of marginal fit of three-unit fixed dental prostheses fabricated using a direct metal laser sintering system and that of three-unit prostheses by a conventional lost wax technique method.[42] They also showed in another study that the gap of the metal cores produced by SLS increased after completion of porcelain firing on the metal core, but the gap was still acceptable clinically.[43] Meanwhile, Sundar,[44] Bhaskaran,[45] Castillo-Oyagüe et al.[46,47] reported the best marginal fit of SLS group than other manufacturing methods. Most studies mentioned above concluded that SLS Co-Cr may be a reliable alternative to the casted base metal alloys to obtain well-fitted crowns.[15, 43-48]

However, there has been little information on the relationship of the finish line design and the marginal fit of the SLS restoration. The purpose of this study was to evaluate the influence of the variation of finish line to the marginal adaptations of metal copings manufactured by SLS technique, milling and digitalized casting. The null hypotheses of this study stated that the finish line design do not influence the absolute marginal discrepancy of metal coping fabricated by three different methods and that the marginal fit of laser sintered coping is similar to that of casted coping and milled coping.

MATERIALS AND METHODS

Fabrication of master models

Two master models were designed by computer program (3D CAD, Dassault Systèmes SOLIDWORKS Corp., Massachusetts, USA) to simulate the complete crown preparation of the mandibular first molar (Fig. 1). Each design was represented on the titanium model by computerized milling (Fig. 2). Each model had 5.0 mm of height, 11.0 mm of maximum mesio-distal width, 10.0 mm of maximum bucco-lingual width and 1.2 mm of marginal width. They had 6 degrees of the convergent angle of axial wall and occlusal appearance of the prepared abutment tooth in common. The difference between two models is the axiogingival internal line angle, which represents the finish line design. One master model has deep chamfer margin with axiogingival internal line angle of 1.2 mm radius and the other one has rounded shoulder margin with axiogingival internal line angle of 0.5 mm radius (Fig. 3).

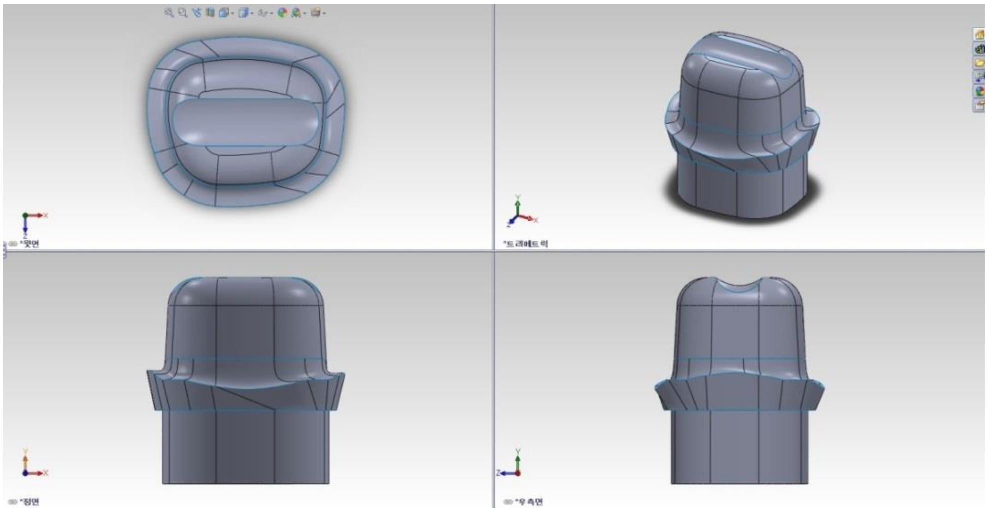


Fig. 1. The design of master model by 3D CAD program.

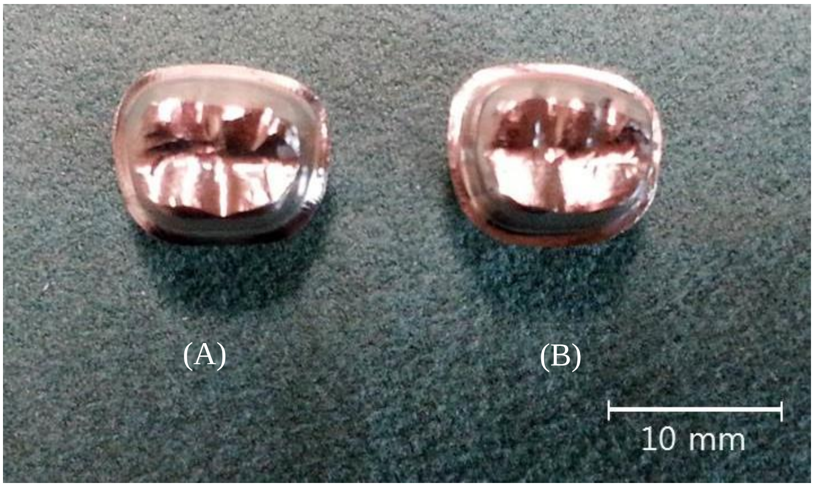
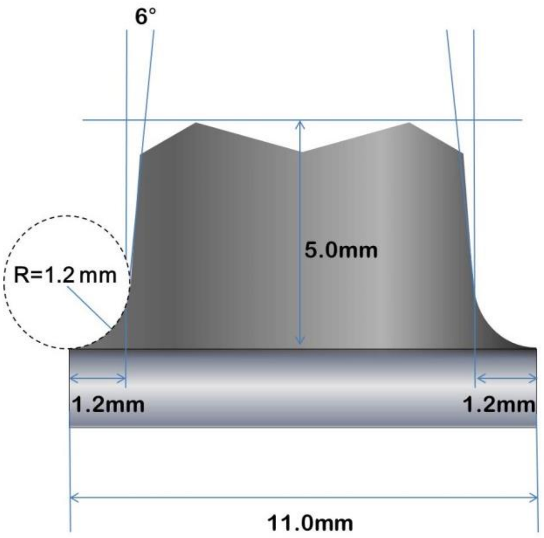
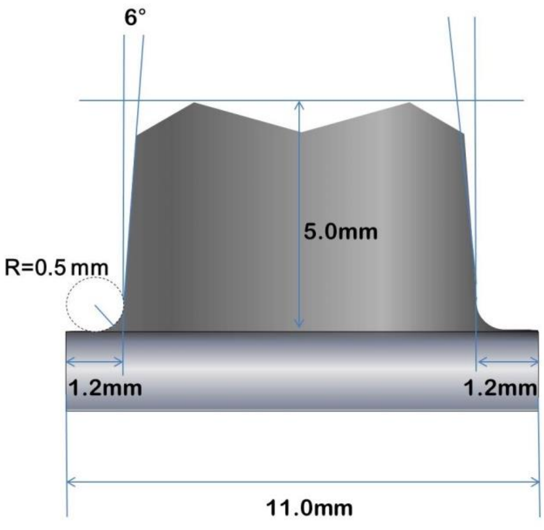


Fig. 2. Titanium master model produced based on the 3D design. (A): Deep chamfer margin. (B): Rounded shoulder margin.



(A)



(B)

Fig. 3. The dimensional design of master model. (A): Deep chamfer margin with axiogingival internal line angle of 1.2mm radius. (B): Rounded shoulder margin with axiogingival internal line angle of 0.5mm radius.

Fabrication of copings

Metal copings for each model were fabricated with three different methods: (1) Selective laser sintering (SLS), (2) CAD/CAM milling and (3) digitalized casting. The workflow of coping fabrication according to the manufacturing method was shown in Fig. 4.

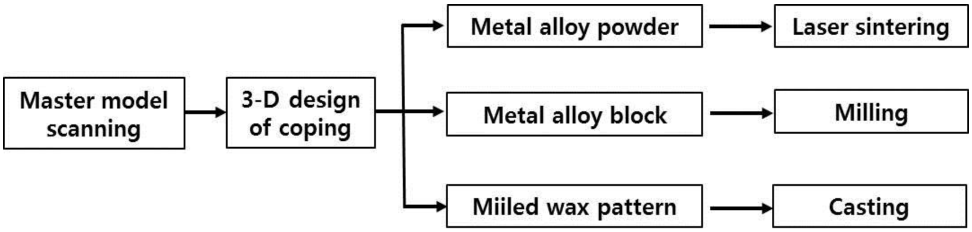


Fig. 4. The workflow of metal coping fabrication according to the manufacturing method.

(1) Selective laser sintering (SLS)

Each model was scanned by dental laser scanner (D-700, 3Shape, Copenhagen, Denmark). A skilled dental technician designed the coping using CAD software (3shape Dental Designer, 3Shape, Copenhagen, Denmark). The thickness of coping was designed to be 0.5mm (the thinnest part has 0.4mm), and the cement space was set at 35µm (the thinnest part has 25 µm) from 1mm above the margin (Fig. 5). This CAD data was transferred to a laser sintering machine (EOSINT M270, EOS GmbH Electro Optical Systems, Krailling, Germany) for fabricating metal frameworks. The laser sintering procedure followed the recommendation of manufacturer (EOS GmbH Electro Optical System, Krailling, Germany) and used cobalt–chromium alloy powder (Co 63.8, Cr 24.7, Mo 5.1, W 5.4, Si 1.0 ; EOS Cobalt Chrome SP2, EOS, Krailling, Germany). The fabrication was under the fixed condition ; a laser power of 200W, scan spacing of 0.1~0.2mm, a laser scan speed of 7.0 m/sec and a layer thickness of 20~30μm. All copings were sandblasted with 250 ㎛ aluminum oxide at a pressure of 3 bar before the heat treatment. The heat treatment was performed in a furnace (LAB24 SF-25, Dongseo Science Co. Ltd, Seoul, Korea) at 800 ℃ during 5 hours for releasing residual internal stress. 12 copings from the deep chamfer margin model (DS group) and 12 copings from the rounded shoulder margin model (RS group) were made respectively (Table 1).

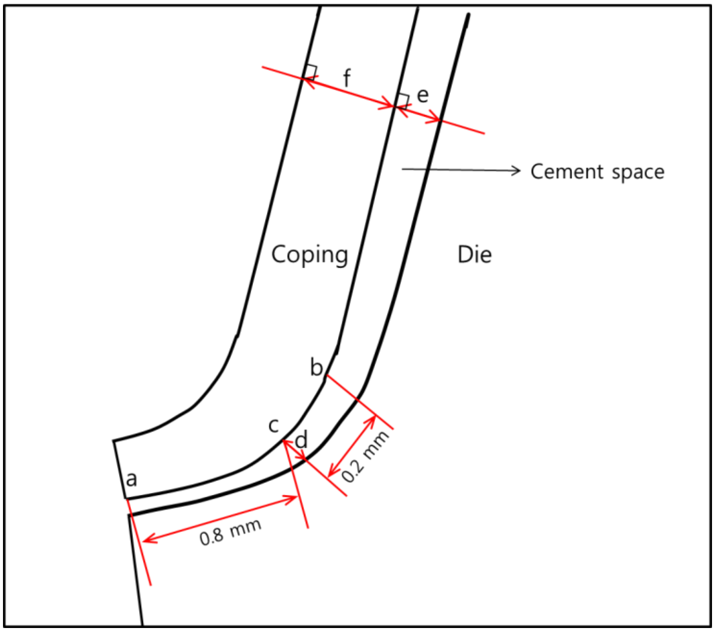


Fig. 5. The cross-sectioned image and sizes of the coping and cement space. (a) Terminal point of margin (b) Setting point of cement space; 1.0mm from terminal point. (b-c) Transition section. (d) Minimum cement space; 25μm. (e) Cement space; 35μm. (f) Thickness of coping; 0.5mm.

(2) CAD/CAM milling

The same scanning data of master models was sent to a simultaneous 5-axis milling machine (PMS5Ⅱ, Dental Plus, Kyeonggi, Korea) which has 50,000RPM/450W spindle for computerized milling. The Co-Cr alloy blocks (Co 62, Cr 30, Mo 6, Si, Mn, Fe, C ; CHROME-COBALT 95H10, Zirkonzahn, South Tyrol, Austria) were milled with milling burs (356SR, NTI, Kahla, Germany), which has 1.0mm ball size and 4° taper, according to the manufacturer’s recommendation. No treatment after fabrication was performed. 12 copings produced from the deep chamfer margin model (DM group) and 12 copings produced from the rounded shoulder margin model (RM group) were made in each group (Table 1).

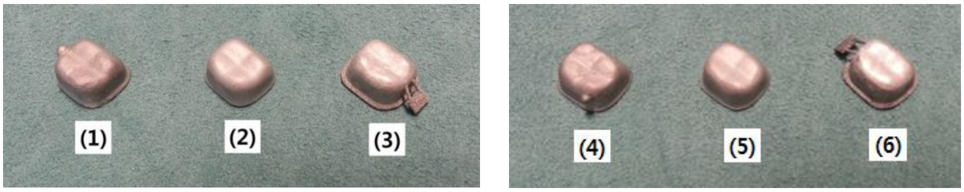
(3) Digitalized casting

To obtain the exactly same wax pattern with copings made by SLS system, the same parameters in the 3D CAD data were sent to a milling center for computerized milling (Milling Unit M5 HEAVY, Zirkonzahn, South Tyrol, Austria) of wax (Easymill Wax, High Dental Korea, Gwangju, Korea) with milling bur (CAD/CAM Bur 2L, Zirkonzahn, South Tyrol, Austria). The milled wax patterns were invested in phosphate-bonded investment material with metal ring (Vaccume furnace, Sejong Dental, Seoul, Korea), and casted with the base metal alloy (NICROMED premium, NEODONTICS, California, USA). The composition of base metal alloy used in this experiment is presented in Table 2. Casting is carried out with induction heating of 50℃ increasing temperature per minute and maximum melting temperature of 820℃, which is in combination with the centrifugal casting machine (SJ CM 01, Sejong Dental, Seoul, Korea) according to the manufacturer's instructions. No additional internal adjustment of the copings was performed except the elimination of casting nodules with rotating instruments. 12 metal copings from the deep chamfer margin model (DC group) and 12 copings casted from the shoulder margin model (RC group) were made in each group (Table 1).

Table 1. Six groups of specimens categorized by finish line design and manufacturing methods.

Manufacturing method	Deep chamfer margin	Rounded chamfer margin
Laser sintering	DS group	RS group
Milling	DM group	RM group
Casting	DC group	RC group

As each group had 12 samples, 72 samples were made in total.



(A) (B)

Fig. 6. Copings produced by three different fabricating methods from two master models. A: Deep chamfer margin group. (1) DC group. (2) DM group. (3) DS group. B: Rounded shoulder margin group. (4) RC group. (5) RM group. (6) RS group.

Table 2. Chemical composition of nonprecious alloy for fabrication of laser sintered, milled and casted metal copings as a percentage according to the manufacturer's instructions (wt %).

Alloy	Co	Ni	Cr	Mo	Si	W	Nb	Al
Laser sintering	63.8	-	24.7	5.1	1.0	5.4		
Milling	62		30	6		Etc. max. 2.0		
Casting	-	73.8	12.2	3.6	3.2		4.6	2.2

Measurements of the specimens

The marginal discrepancy was defined as the shortest distance between the margin of the preparation and the edge of the crown margin, therefore an examiner measured the perpendicular distance from a determined reference point to the edge of the metal coping in this study. Each master model has the measurement areas on mesial, buccal, distal and lingual site of the margin. Measurement area of 3000 μm were determined on each site and marked on the margin of the model. Each area has 10 reference points of P1 ~ P10 which have 300 μm distance between adjacent points. The average value of 10 measurements on a site represented the mean marginal gap of the site (Fig. 7).

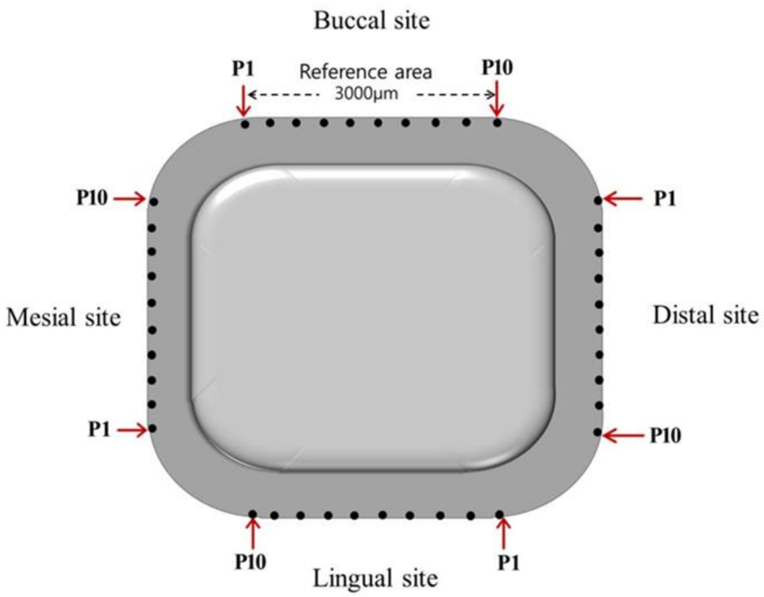


Fig. 7. Reference points on the margin of the master model. The master model has four measurement areas on the margin at mesial, buccal, distal and lingual site, respectively. Each measurement area has 10 reference points of P1 ~ P10 which have 300 μm distance between adjacent points.

A single expert examiner measured all the specimens using the confocal laser scanning microscope (CLSM) (LSM 5 PASCAL, Carl Zeiss MicroImaging GmbH, Göschwitzer, Germany) at the magnification 150. Specimens were seated to the original master die with maximum hand pressure and fixed using rubber adhesive (BluTack, Bostik, Leicester, UK). The prepared specimen was mounted onto the measuring device and the examiner controlled finely the angle of long axis of specimen at every measuring for the laser beam to bisect perpendicularly the connecting line of two determined points (Fig. 8). The distance between two points was calibrated by one experienced engineer according to the manufacturer's instructions (Fig. 9). Each specimen was measured at 40 reference points along the circumferential margin and 2880 measurements were performed on the 72 specimens in total.

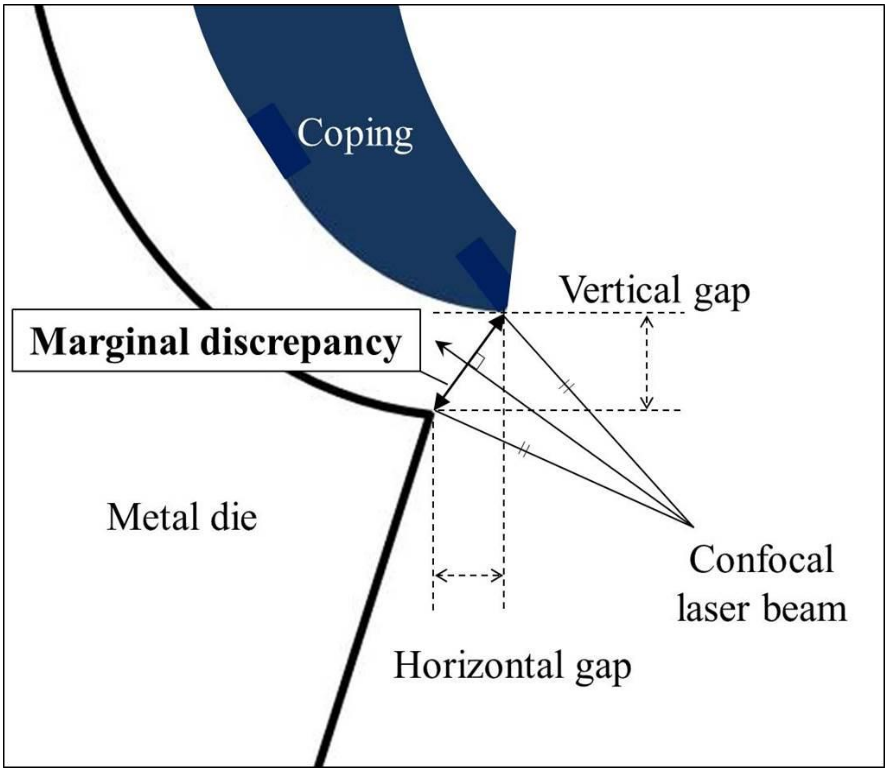


Fig. 8. Schematic section view of a specimen showing the marginal discrepancy measured in this study and the principle of measuring the distance. The marginal discrepancy is determined as the angular combination of marginal gap between the margin of the coping and the cavosurface margin(?) of the abutment. The laser beam bisects perpendicularly the connecting line of two target points.

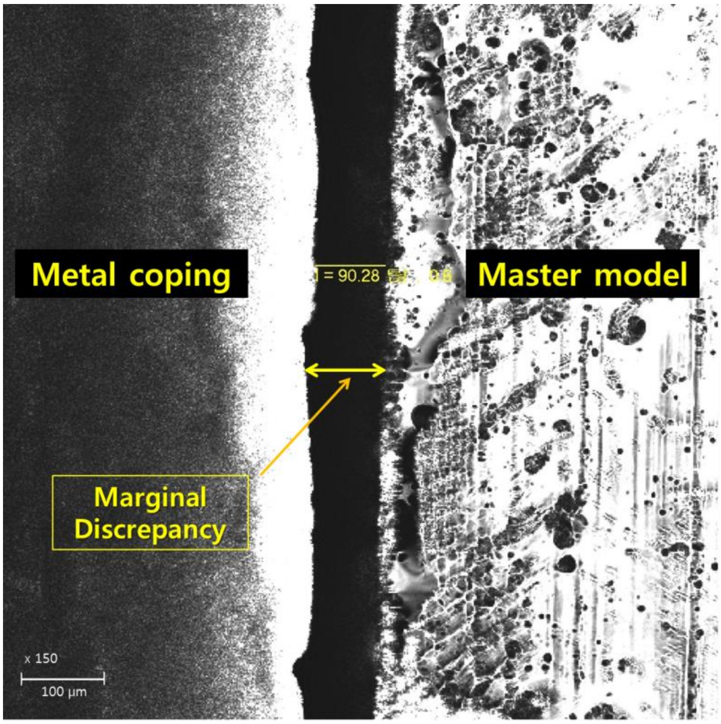


Fig. 9. Demonstration of the measurement of marginal gap by the confocal laser scanning microscope at x 150 magnification.

Statistical analysis

Shapiro-Wilk test was conducted to examine the normality of the data distribution. The normality of sample data was rejected upon the basis of the visual inspection of box plots of data distribution and the result of the supplementary Shapiro-Wilk test ($p<0.05$), therefore non-parametric statistics was applied to data analysis in this study.

Kruskal-Wallis Tests, which can be used whether the data follow the normal distribution or not, was conducted to evaluate the overall statistical significance of the three different manufacturing methods regarding the marginal discrepancy under two different finish lines separately.

Once statistical significance was confirmed from the overall test, Wilcoxon test was followed for multiple comparisons of each pair of three different manufacturing methods regarding the marginal gaps of the metal copings. The JMP version 11 (SAS Institute Inc., North Carolina, USA) was used for all statistical analyses at a significance level of 5%.

RESULTS

1. Deep chamfer margin

The mean values and standard deviations of the marginal discrepancies of three groups with deep chamfer margin are shown on Table 3. The distribution and median value of sample data was shown in Fig. 10. SLS group showed the best marginal fit among three groups at mesial, labial, lingual site and casting group had better marginal fit than other groups at distal site. The mean average marginal gaps are significantly different among the three different fabricating methods at every site (p<.05) (Table 3).

SLS group had the smallest mean marginal discrepancy and standard deviation at all position into one. The value was 11.8±7.4 μm, which was smaller than 18.8±20.2 μm of casting group and 53.9±27.8 μm of milling group. SLS group had more homogeneous marginal gap than other groups and the differences among the three groups were statistically significant in total (p<.0001).

Table 3. Mean (SD) value of absolute marginal discrepancy for four sites of the metal copings with deep chamfer margin by Kruskal-Wallis Tests (unit: μm)

Site	SLS DS group	Milling DM group	Casting DC group	*p*-value
Mesial	17.8(8.8)	45.2(20.2)	45(26)	0.0073
Labial	6.8(1.5)	61.4(34.9)	16(5.3)	<.0001
Distal	16.8(5.1)	32.2(17.7)	7.6(1.6)	<.0001
Lingual	5.9(1.3)	76.7(13)	6.4(2)	<.0001
Total	11.8(7.4)	53.9(27.8)	18.8(20.2)	<.0001

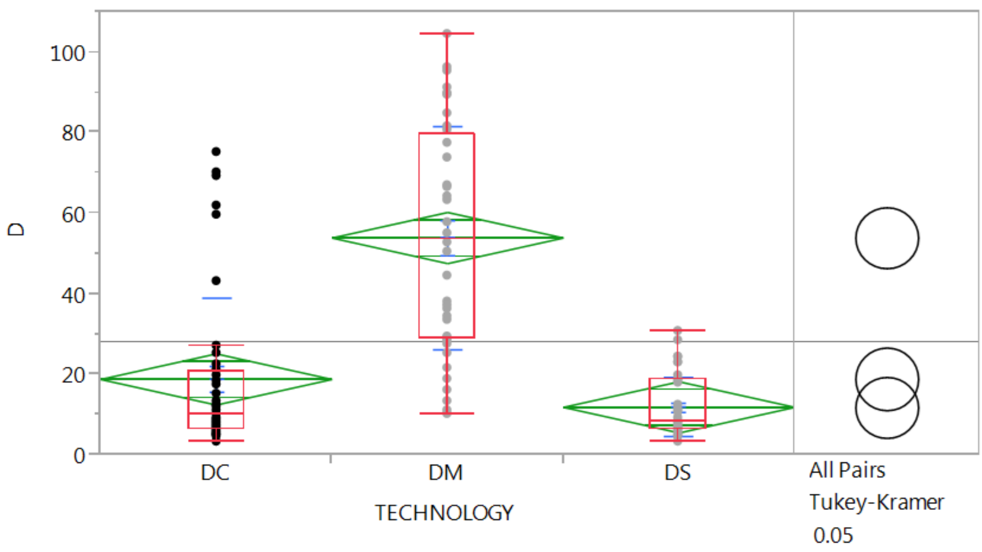


Fig. 10. Box plots of population distribution and mean value of the marginal discrepancy of Co-Cr copings with deep chamfer margin according to the manufacturing methods. Line in each box represents median value of each group. The diagram showed that the data of marginal gap were not normally distributed (α=.05).

Based on the above result, multiple comparisons for each pair of three manufacturing methods were performed additionally and the results were shown in Table 4. The 9 pairs of total 12 pairs represented statistical significance and only labial site represented the significant differences about all of the three comparisons (Table 4).

Table 4. Comparison of the mean marginal discrepancy of three manufacturing methods at each site (DC: casting, DM: milling, DS: selective laser sintering)

Site	Comparison	*p*-Value
Mesial	DM >[§] DC	1.0000
	DS < DC	0.0257*
	DS < DM	0.0022*
Labial	DM > DC	0.0006*
	DS < DC	0.0002*
	DS < DM	0.0002*
Distal	DS > DC	0.0002*
	DM > DC	0.0002*
	DS < DM	0.0640
Lingual	DM > DC	0.0002*
	DS < DC	0.5708
	DS < DM	0.0002*

[§] A sign of inequality means the result of the comparison of the mean marginal gap values of two groups, therefore the smaller means the better marginal fit.

* The mean difference is statistically significant at the level of .05.

2. Rounded shoulder margin

The mean values and standard deviations of the marginal gap of the metal copings with rounded shoulder margin are shown on Table 5. The distribution and median value of sample data was shown in Fig. 11. The result revealed that the marginal gaps are significantly different among the three different fabricating methods at mesial, buccal, distal and lingual site. SLS group showed the best marginal fit among three groups at every site (p<.05).

The mean average marginal gap distance was 6.3±3.5 μm in laser sintering group, 48.6±30.1 μm in milling group and 33±20.5 μm in casting group regarding the total circumferential margin. The result was also same as deep chamfer margin in that laser sintered copings showed the smallest mean marginal gap and homogeneous marginal gap. Casting and milling method followed that in order (p<.0001) (Table 5).

Table 5. Mean (SD) value of absolute marginal discrepancy for four sites of the metal copings with rounded shoulder margin by Kruskal-Wallis Tests (unit: μm)

Site	SLS (RS group)	Milling (RM group)	Casting (RC group)	*p*-value
Mesial	8.1(1.7)	44.6(38)	43.9(13.6)	0.0005
Labial	9.1(5)	63.7(36.7)	49.8(18)	<.0001
Distal	4.3(1.1)	51.1(19.4)	28.1(15.5)	<.0001
Lingual	3.6(1)	35.1(17.8)	10.3(4.5)	<.0001
Total	6.3(3.5)	48.6(30.1)	33(20.5)	<.0001

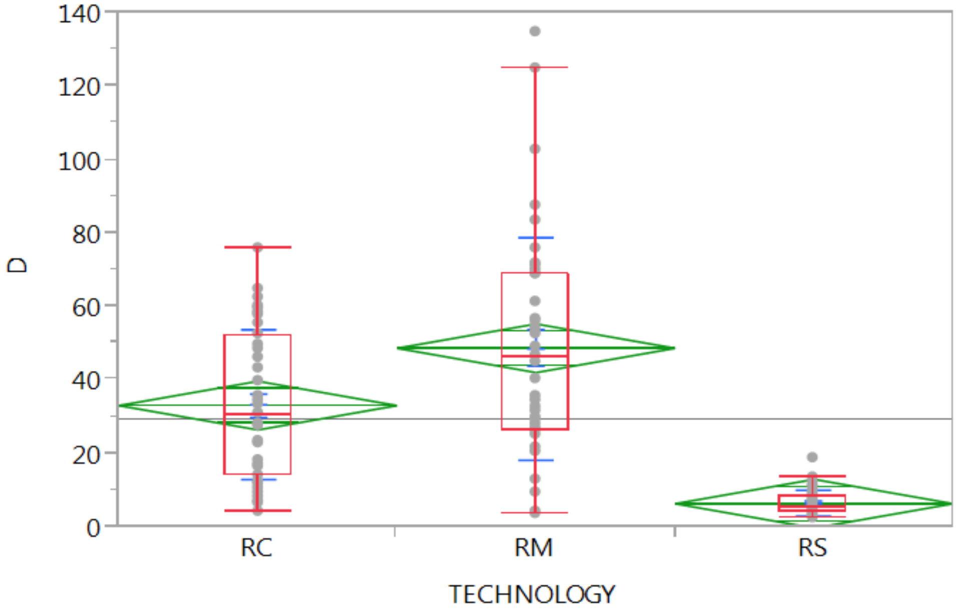


Fig. 11. Box plots of population distribution and mean value of the marginal discrepancy of Co-Cr copings with rounded shoulder margin according to the manufacturing methods. Line in each box represents median value of each group. The diagram showed that the data of marginal gap were not normally distributed (α=.05).

Based on the above result, multiple comparisons for each pair of three manufacturing methods were performed additionally and the results were shown in Table 6. The 10 pairs of total 12 pairs represented statistical significance and distal and lingual site represented the significant differences about all of the three comparisons (Table 6).

Table 6. Comparison of three manufacturing methods regarding the marginal discrepancy at each site in rounded shoulder margin group (RC: casting, RM: milling, RS: selective laser sintering)

Site	Comparison	*p*-Value
Mesial	RM >[§] RC	0.5205
	RS < RC	0.0058*
	RS < RM	0.0002*
Labial	RM > RC	0.4727
	RS < RC	0.0002*
	RS < RM	0.0002*
Distal	RS < RC	0.0257*
	RM > RC	0.0002*
	RS < RM	0.0002*
Lingual	RM > RC	0.0058*
	RS < RC	0.0008*
	RS < RM	0.0004*

[§] A sign of inequality means the result of the comparison of the mean marginal gap values of two groups, therefore the smaller means the better marginal fit.

* The mean difference is significant at the level of .05. The mean marginal discrepancy of sintered copings was smaller than those of casted and milled copings at all marginal sites.

3. Comparison of two different finish line design regard to marginal gap

The comparison of the mean marginal discrepancy of nonprecious alloy copings with two different margins was conducted regard to the same manufacturing method. The difference of marginal gap between deep chamfer margin and rounded shoulder margin was compared at each site and in total.

3.1 DS vs RS (laser sintered copings)

The average marginal gaps of laser sintered copings are shown by part in table 7. Deep chamfer margin represent larger gap than rounded shoulder margin at mesial, distal and lingual site and the differences were statistically significant (p<.05). The opposite result was shown at labial site and the difference was not statistically significant (p=0.5453). Meanwhile, lingual site had the best marginal fit among all site in both of two marginal designs (5.9±1.3 μm for deep chamfer margin and 3.6±1 μm for rounded shoulder margin). According to total mean values of all site into one, deep chamfer margin (11.8±7.4 μm) exhibited significantly greater marginal discrepancy than rounded shoulder margin (6.3±3.5 μm) (p<.0001)

Table 7. Comparison of absolute marginal gap between two different finish lines of laser sintered copings (DS vs RS).

Site	Deep chamfer margin	Rounded shoulder margin	*p*-Value
Mesial	17.8(8.8)	8.1(1.7)	0.0140*
Labial	6.8(1.5)	9.1(5)	0.5453
Distal	16.8(5.1)	4.3(1.1)	0.0002*
Lingual	5.9(1.3)	3.6(1)	0.0015*
Total	11.8(7.4)	6.3(3.5)	<.0001*

3.2 DM vs RM (milled copings)

The average marginal gaps of milled copings are shown by part in table 8. Deep chamfer margin represented smaller gap than rounded shoulder margin at mesial site (*p*=0.5967) and deep chamfer margin represented larger gap than rounded shoulder margin at labial site (*p*= 0.8798), however those differences were not statistically significant (Table 8). Deep chamfer margin showed smaller gap than rounded shoulder margin at mesial site (*p*=0.0413) and deep chamfer margin showed greater gap than rounded shoulder margin at labial site (*p*=0.0002) resulting in statistically significant differences. Meanwhile, distal site had the best marginal fit among all site in deep chamfer design (32.2±17.7 μm) , whereas lingual site had the best marginal fit among all site in rounded shoulder design (35.1±17.8 μm). In total mean values, the difference between deep chamfer margin (53.9±27.8 μm) and rounded shoulder margin (48.6±30.1 μm) was not statistically significant (*p*=0.279) (Table 8).

Table 8. Comparison of absolute marginal gap between two different finish lines of milled copings (DM vs RM).

Site	Deep chamfer margin	Rounded shoulder margin	*p*-Value
Mesial	45.2(20.2)	44.6(38)	0.5967
Labial	61.4(34.9)	63.7(36.7)	0.8798
Distal	32.2(17.7)	51.1(19.4)	0.0413*
Lingual	76.7(13)	35.1(17.8)	0.0002**
Total	53.9(27.8)	48.6(30.1)	0.2790

3.3 DC vs RC (digitalized casting)

The average marginal gaps of digitalized casted copings are shown by part in table 9. Deep chamfer margin represented smaller gap than rounded shoulder margin at all site except mesial site. The differences between two marginal finish lines according to the marginal gap were statistically significant at labial site (*p*= 0.0004) and distal site (*p*=0.0003) (Table 9). According to total mean values of all site into one, deep chamfer margin (18.8±20.2 μm) exhibited significantly greater marginal discrepancy than rounded shoulder margin (33±20.5 μm) (*p*=.0004)(Table 9).

Table 9. Comparison of absolute marginal gap between two different finish lines of digitalized casted copings (DC vs RC).

Site	**Deep chamfer margin**	**Rounded shoulder margin**	***p*-Value**
Mesial	45(26)	43.9(13.6)	0.8206
Labial	16(5.3)	49.8(18)	0.0004*
Distal	7.6(1.6)	28.1(15.5)	0.0003*
Lingual	6.4(2)	10.3(4.5)	0.0696
Total	18.8(20.2)	33(20.5)	0.0004*

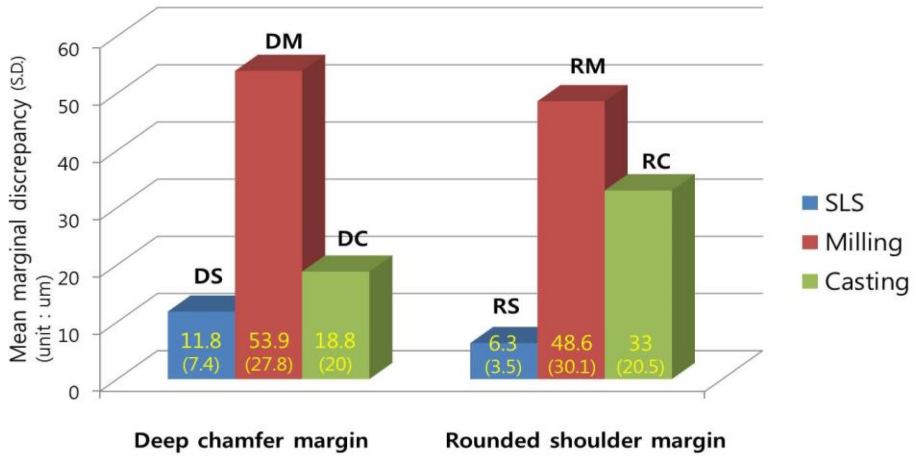


Fig. 12. Comparison of mean marginal gap between groups fabricated by different methods. The difference of the marginal fit among three methods was statistically significant for both finish line designs. The laser sintered copings showed the narrowest marginal gap among three groups regardless of marginal design. The milled copings showed the widest marginal gap among three groups regardless of marginal design.

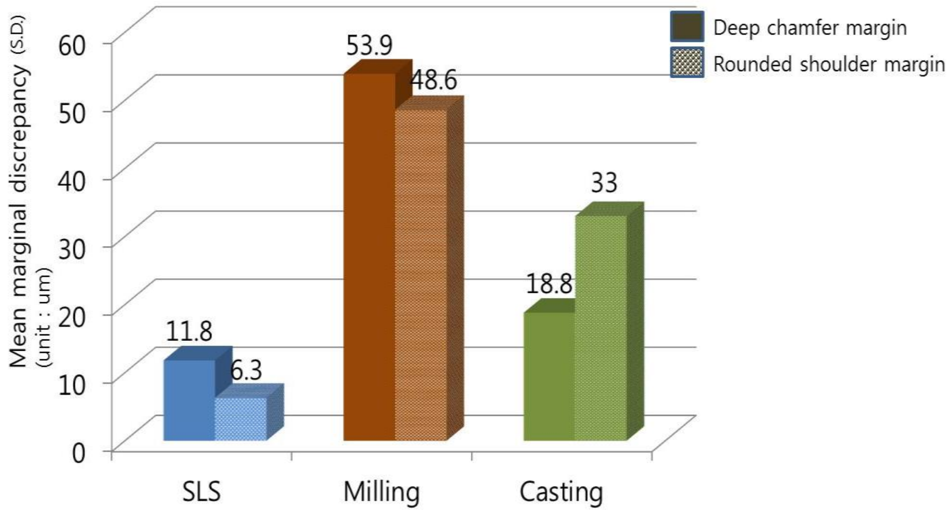


Fig. 13. Comparison of mean marginal gap between two different finish lines. Rounded shoulder margin has better fit than deep chamfer margin in SLS group and milling group, while the opposite result was shown in casting group. The differences were statistically significant in SLS group (p<.0001) and casting group (p=.0004).

DISCUSSION

The present study was conducted to evaluate the influence of finish line design on the marginal fit of nonprecious metal alloy coping. With this view, metal copings manufactured by three different methods – selective laser sintering, milling and digitalized casting - were compared regard to the marginal discrepancy. From the analysis of the data, the first null hypothesis was rejected that the finish line design do not influence the marginal gap of nonprecious metal alloy coping, and the second null hypothesis was rejected that the marginal fit of laser sintered metal alloy coping was similar to that of casted coping and milled coping.

This study tried to simulate the prepared abutment of human tooth as master models. For that, a resin tooth was prepared first, which has the average size and shape of human tooth, and then a design of master model was implemented based on the outline of prepared resin tooth. This procedure is needed because the human tooth is not like cylinder shape and the appearance of occlusal surface is not flat. There are some studies with similar concept to this study, however they used a simplified master model or a prepared ivory tooth or a particular tooth of human.[40-43] As the authors verified ahead that the accuracy of the abutment preparation influenced the quality of marginal fit in previous study,[49] the master models of this study simulated the abutment from the average human tooth and the preparation procedure was substituted to computer designing of master model.

The procedure explained above could be possible with three-dimensional designing work using computer program (3D CAD, Dassault Systemes SOLIDWORKS Corp., Waltham, MA, USA). 3D CAD is the world’s most popular computer designing software which utilizes a parametric feature-based approach to create models. The designing program consists of geometry such as points, lines, arcs, conics and splines, and implements relations such as tangency, parallelism, perpendicularity and concentricity. That means a possibility of building a model corresponding with the principle of abutment preparation. Therefore, the models of present study have smooth finish line at all around the margin, regular radius of the axiogingival internal line angle and steady axial wall taper circumferentially. This point makes this study meaningful in that inter-experimenter variability was excluded. This is because that the authors assured the fact in the previous study that the hand preparation revealed the irregular wave of running of the finish line and inconsistency of axial wall taper and radius, which may affect the clinical results.[49]

The marginal discrepancies of metal copings regard to the finish line design were significantly different in SLS group and casting group (Table 7, 9). Copings with rounded shoulder margin showed better marginal fit than deep chamfer margin in SLS group, whereas the opposite result was shown in casting group. The curvature radius of the axiogingival internal line angle may affect the marginal adaptation of copings. The rounded shoulder margin design has smaller curvature radius than that of deep chamfer margin. SLS technique showed the highest accuracy among three manufacturing methods (Fig. 10) and that means it has more excellent ability to interpret fine design than other methods. Meanwhile, there was no significant difference between two finish lines in milling group which has the largest average marginal gap (Table 8) (Fig. 10). The relatively inferior accuracy of milling method may be a limitation to reflect the fine difference of the design between the two finish lines.

For the comparison of manufacturing method, the analysis showed significantly different mean marginal discrepancies among three methods (Table 3, 5). Multiple comparisons among them revealed that the marginal fit was good in order of SLS, casting and milling regardless of finish line design (Table 3, 5) (Fig. 10). The findings of many other studies are in agreement with the results of the current study,[44-48] although Kim et al. reported that the marginal gap measured in SLS group was greater than that of casting group.[42,43] The excellent marginal fit of laser sintered coping was explained in that the fabricating process is simplified and do not need tools such as milling bur. Moreover, compared with conventional lost wax technique which consists of many procedures, the SLS technique eliminates the inter-operator variation and is almost without porosity.[19,50] The reason of the largest marginal gap in milling group may be explained that it is more difficult to mill the metal alloy block precisely due to its hardness. The resistance of the milling axis and its vibration could affect the delicate procedure, compared with the milling of the soft pattern wax used in digitalized casting method. Moreover, wear of milling bur reduces the cutting efficiency and fineness, which reduce the consistency of the accuracy. These factors may cause the large standard deviation of data in both milling group and casting group, which consists of milling procedure in common. That was contrast to the small standard deviation of laser sintered copings.

According to the marginal gap for each site, five groups among six groups, only except DM group, exhibited the best marginal fit on lingual site (Table 3, 5). The outline of lingual margin of abutment model simulating mandibular first molar is almost like straight line compared with the other sites. The more complex design induces the more probability of occurrence of errors. Meanwhile, there was no consistency regard to the site of the most inferior marginal fit in DS, DM and DC group. On the other hand, average marginal fit of labial site was the worst in RS, RM and RC groups in common (Table 3, 5). It may be due to the volume and the height of buccal cusps of rounded shoulder margin model, because the larger volume of material occurs the more amount of contraction and the length from the buccal cusp tip to the labial margin is longer and more curved than the length from lingual cusp tip to the lingual margin.

Many studies about the marginal fit of various crowns have been reported, however it is difficult to compare the studies directly because there are many concepts regard to the marginal discrepancy.[18] Marginal gap is the shortest distance from the coping to the die surface. Horizontal marginal gap is the horizontal marginal misfit measured perpendicular to the path of draw of the coping and vertical marginal gap is the vertical marginal misfit measured parallel to the path of draw of the coping. Absolute marginal discrepancy means the distance measured from the margin of the coping to the cavosurface angle of the die as the angular combination of the marginal gap.[51] In this study, the absolute marginal discrepancy was determined as the representation of marginal fit, because the other concepts mentioned above are not the real distance but visual distance (Fig. 6). Moreover, vertical marginal gap cannot be measured if the margin of coping hangs over the prepared margin of the abutment, however the absolute marginal discrepancy is available in case of the over-hanging margin.

The marginal fit was assessed by measuring the shortest distance from the determined reference points to the edge of coping with a confocal laser scanning microscope (CLSM) in this study. CLSMs can measure the exact absolute marginal discrepancy, because the apparatus can focus two objects at the same time only when the distances between the laser beam source and the objects are same. That means the laser beam bisects the connecting line between two points perpendicular (Fig. 6). However, the limitation of this method is that it cannot be used for measuring of internal gap. Many other studies used replica technique which is the method of measuring the thickness of the intervention between abutment and the coping.[52,53] Disadvantage of this method is the low reliability of the value by sectioning of the specimen. The small number of measurement point and the ambiguous boundary of intervention material on the microscopic view are the serious limitation of replica technique.[43]

In this study, the values of the marginal gap was smaller than those of other studies in general. örtorp et al.[48] presented the mean cement film thickness of 84㎛ on 3-unit fixed prostheses. Kim et al. reported the marginal gap of 75.0㎛ measured with the intervention of light body silicone for replica Technique.[43] Castillo-Oyague et al. reported the range of 27.2~61.6㎛ for misfit of implant supported crown coping obtained by laser sintering luted with several kind of agents.[46] The main reason of that the values of marginal gap in this study was somewhat smaller than other studies is no intervention of material between coping and model. The intervention of a luting material hinder the coping from sitting on the abutment fully and the viscosity and flowability of many various cement materials effect differently on it.[44,46,47] Another reason can be that the occlusal surface of master model followed anatomic preparation. Syed et al. reported that anatomical occlusal preparation designs resulted in better marginal and internal adaptation of Zr copings than non-anatomical occlusal design.[54] In addition, master model fabrication was based on the computer design which makes the procedure more accurate than hand preparation.[49]

Several studies about SLS technology compared laser sintered Co-Cr alloy and casted Co-Cr alloy, because Co-Cr alloy is the only nonprecious metal alloy that

SLS technic handles at present. The results suggested that the marginal distortion during the casting of Co-Cr alloy may be overcome through the use of SLS method.[16,17,45,48] Meanwhile, some other studies were conducted with various materials. Quante et al. compared the marginal and internal fit between SLS Co-Cr crown and SLS Au-Pt crown, and resulted comparable marginal fit between the two alloys.[15] Ucar et al. evaluated the internal fit of SLS Co-Cr crown, casted Co-Cr crown and casted Ni-Cr crown, and the result of difference was not statically significant (p=.42).[7] Castillo-Oyagüe et al. assessed misfit of implant supported crown and three-unit bridge, and they reported SLS crown has the best fit and cast Co-Cr performed equally well to cast Ni-Cr crown.[46,47] Sundar et al. reported that the marginal fit of SLS Co-Cr coping has better marginal fit than cast Ni-Cr coping.[44] This result is same as the result of present study, however the producing method of casted Ni-Cr coping was different. Sundar's Ni-Cr coping was fabricated by conventional lost wax technique, while this study used the same computerized design of coping with SLS coping and milled wax pattern by CAD/CAM. This point is meaningful because the consistency of the thickness of coping and cement space influence the accuracy of fit. Soriani et al. studied the effect of thickness of die spacer on the marginal fit of copings and concluded that there was a statistically significant difference (p<0.05) according to the various thickness of die spacer.[55]

In this study, the abutment preparations were digitalized and one professional examiner performed the measurement of the specimens so that the performance bias and inter-examiner variability did not occur. For future study, the comparison of the marginal adaptation of the metal coping between before and after of porcelain firing could be considered and the new experimental design to measure both marginal and internal gap are required.

CONCLUSION

Within the limitation of this study, the following conclusions were drawn : The variation of finish line design influenced the marginal adaptation of laser sintered metal coping and casted metal coping. Rounded shoulder margin shows better fit than deep chamfer margin in laser sintered coping, while deep chamfer margin has better marginal fit than rounded shoulder margin in casted copings, and the differences were statistically significant in both methods. Milled copings with rounded shoulder margin shows better fit than deep chamfer margin, but no significant difference of the marginal adaptation was found between those two margin designs. In addition, the marginal fit of base metal coping differed depending on the site of the margin. Especially, there was a tendency that the lingual margin has the better marginal fit than other sites in rounded shoulder margin groups.

According to the manufacturing method, SLS system showed the best marginal adaptation of base metal coping in comparison with milling and casting method and it implemented homogeneous margin. On the contrary, milling method showed relatively inferior marginal accuracy than SLS system or digitalized casting method and exhibited low ability to implement the difference of finish line designs. Based on the findings of the present study, it may be recommended to choose the adequate manufacturing method of metal coping depending on the finish line design in the clinical aspect.

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국문초록

CAD/CAM 을 활용하여 3D printing, milling, casting 방법으로 제작한 비귀금속 합금 코핑의 지대치 변연 형태에 따른 변연 적합도의 변화

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김 서 랑

연구 목적 : 본 연구의 목적은 레이저 신터링, 컴퓨터 밀링, 주조의 세 가지 방법으로 제작된 비귀금속 합금 코핑의 변연 형태에 따른 변연 적합도의 변화를 관찰하는 데 있다. 이를 위해서, 각각 deep chamfer margin 과 rounded shoulder margin 을 가지는 두 모델을 제작하고, 위의 두 가지의 변연에 대하여 제작방식 간에 적합도의 차이도 비교해보고자 하였다.

재료 및 방법: 서로 다른 두 개의 변연 형태를 정확히 재현하기 위해 3D CAD 를 이용하여 지대치 삭제의 원칙에 따라 지대치를 디자인한 다음, 티타늄 블럭을 컴퓨터 밀링하여 주모델을 제작하였다. 각각의 모델에 대하여 위의 3 가지 제작 방법으로 비귀금속 합금 코핑을 12 개씩 제작하여, 총 72 개의 코핑을 제작하였다. 각 코핑은 지대치에 적합시켜서 공초점 레이저 주사 현미경으로 근심, 협측, 원심, 설측 변연의 변연 적합도를 150 배율로 측정하였다.

결과: 레이저 신터링으로 제작한 코핑의 평균 변연 격차는 deep chamfer margin 에서 11.8±7.4 μm, rounded shoulder margin 에서 6.3±3.5 μm 였고, 그 차이는 통계적으로 유의했다 (p<.0001). 컴퓨터 밀링으로 제작한 그룹에서는 deep chamfer margin 에서 53.9±27.8μm, rounded shoulder margin 에서 48.6±30.0 μm 였고, 변연 형태에 따른 유의한 차이가 없었다 (p=.279). 주조 방법으로 제작한 그룹은 deep chamfer margin 에서 18.8±20.2 μm, rounded shoulder margin 에서 30±20.5 μm 였고, 그 차이는 통계적으로 유의했다 (p=.0004). 한 편, 같은 변연 형태에 대한 세 가지 제작 방식 간의 정밀도 차이는 두 종류의 변연 형태에서 모두 유의하게 나타났는데, 레이저 신터링 방법이 가장 우수하였고, 다음으로 주조와 밀링의 순으로 변연 적합도가 양호하였다.

결론 : 이번 실험을 통하여, 다음과 같은 결론을 얻었다.

1. 변연의 형태에 따른 변연 적합도는 레이저 신터링이나 주조 방법으로 제작된 금속 코핑의 경우 변연 형태에 따라 유의한 차이가 있었다.

2. 레이저 신터링으로 제작한 금속 코핑에서 rounded shoulder margin 이 deep chamfer margin 보다 우수한 변연 적합도를 보였다.

3. 주조 방법으로 제작한 금속 코핑의 경우는 deep chamfer margin 이 rounded shoulder margin 보다 우수한 변연 적합도를 보였다

4. 밀링 방법으로 제작된 금속 코핑은 마진 형태에 따라 변연 적합도가 유의하게 달라지지 않았다.

5. 제작 방식에 따른 코핑의 변연 적합도는 레이저 신터링이 가장 양호하였고, 그 다음 주조 방법과 밀링 방법 순으로 변연 적합도가 양호하였다.

이번 연구를 통해, 지대치의 변연 형태에 따른 금속 코핑의 변연 적합도의 변화를 관찰하였으며, 레이저 신터링으로 제작하거나 디지털 밀링한 왁스 패턴을 캐스팅한 경우에는 상관 관계가 있음을 확인하였다. 임상에 적용함에 있어 지대치의 변연 형태를 고려하여 금속 코핑의 제작 방법을 결정하는 것이 추천된다.

주요어; CAD/CAM , 3D printing, 레이저 신터링, 비귀금속 합금 코핑, 변연적합도

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